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Universality of Colour-Emotion Associations

Jonauskaitė Domicelė

UNIL | Université de Lausanne

FACULTÉ DES SCIENCES SOCIALES ET POLITIQUES

INSTITUT DE PSYCHOLOGIE

Universality of Colour-Emotion Associations

THÈSE DE DOCTORAT

présentée à la
Faculté des sciences sociales et politiques
de l'Université de Lausanne

pour l'obtention de grade de
Docteure en psychologie

par

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Le Décanat de la Faculté des sciences sociales et politiques de l'Université de Lausanne, au nom du Conseil et sur proposition d'un jury formé des professeurs

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- C. Alejandro PARRAGA, co-directeur de thèse, Professeur à la Universitat Autònoma de Barcelona
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- Paul SOWDEN, Professeur à la University of Winchester
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autorise, sans se prononcer sur les opinions de la candidate, l'impression de la thèse de Madame Domicele JONAUSKAITE, intitulée :

« Universality of Colour-Emotion Associations »

Marie SANTIAGO DELEFOSSE
Doyenne

Lausanne, le 26 mai 2021

Domicelė
JONAUSKAITĖ

Universality of Colour-Emotion Associations

DOCTOR OF PHILOSOPHY THESIS

Institute of Psychology
University of Lausanne

LAUSANNE, 2021

Abstract in English

For over 100 years, popular and scientific communities have suggested that colours have psychological and affective implications. We *feel blue* and *see red*; we wear *white* to weddings and *black* to funerals. Could such arbitrary associations between colours and emotions also reflect fundamental aspects of the mind? Or are they symbolic associations, culturally transmitted through our languages and traditions? In the four empirical chapters, I used the same methodology to test universality and stability of colour-emotion associations.

In Chapter 2, I observed universal patterns in colour-emotion associations across 30 nations, with an average cross-cultural similarity of 88%. Some local differences were apparent too, as similarity was greater when nations were linguistically or geographically closer. In Chapter 3, Swiss French-speaking participants associated similar emotions with colour terms and colour patches, demonstrating stability across the modes of colour presentation. In Chapter 4, participants who lived further away from the equator and in rainier countries were more likely to associate *yellow* with *joy*, showing that one's experience with sunshine was important for *yellow-joy* associations. In Chapter 5, colour-blind Swiss participants associated similar emotions with colour terms or patches as non-colour-blind participants, suggesting that colour-emotion associations in adults were stable irrespective of perceptual realities.

The four studies led to two major conclusions. First, colour-emotion associations are universal and stable with minor differences across nations, colour presentation modes, or different perceptual experiences. Second, colour-emotion associations have a strong conceptual component. These associations seem to be abstract rather than driven by direct visual or affective experience. The four studies enabled me to propose the Colour Connotation Theory, presented in the discussion. Using this theory, I provide suggestions for the mechanisms driving colour-emotion associations, reason how they are connected with other constructs (preferences, cross-modal associations, symbolism) and suggest how colour-emotion associations might lead to colour-related behaviours. More broadly, these studies help bridging the gap between empirical knowledge and practical applications of colour, which are of interest to specialists in design, marketing, communication, health sectors, and others.

Résumé en Français

Depuis plus de 100 ans, les communautés populaires et scientifiques suggèrent que les couleurs ont des implications psychologiques et affectives. De telles associations entre les couleurs et les émotions pourraient-elles refléter des aspects fondamentaux de l'esprit ? Ou s'agit-il d'associations symboliques, transmises culturellement par nos langues et nos traditions ? Durant quatre chapitres empiriques, en utilisant systématiquement la même méthodologie, j'ai testé si les liens couleurs-émotions sont universelles et stables.

Dans le chapitre 2, j'ai observé des tendances universelles d'associations couleurs-émotions. Dans 30 pays, il y avait une similarité interculturelle moyenne de 88%. Certaines différences locales sont également apparues : la similarité était plus grande lorsque les nations sont plus proches linguistiquement ou géographiquement. Dans le chapitre 3, les participants suisses romands ont associé des émotions similaires aux termes de couleur et aux carrées de couleur, démontrant ainsi une stabilité dans les différents modes de présentation des couleurs. Dans le chapitre 4, j'ai montré que les participants vivants plus loin de l'équateur et dans des pays plus pluvieux étaient plus susceptibles d'associer le *jaune* à la *joie*. Ceci montre que l'expérience du soleil est importante pour ces associations. Dans le chapitre 5, des participants suisses daltoniens ont associé des émotions similaires aux termes ou aux carrées de couleur que les participants non daltoniens. Ceci suggère que les associations d'émotions de couleur chez les adultes sont stables, indépendamment des réalités perceptives.

Les quatre études ont abouti à deux conclusions majeures. Premièrement, les associations couleurs-émotions sont universelles et stables, avec des différences mineures entre les nations, les modes de présentation ou les différentes expériences perceptives. Deuxièmement, les associations couleurs-émotions ont une forte composante conceptuelle. Elles semblent être abstraites, plutôt que guidées par une expérience visuelle ou affective directe. En utilisant la nouvelle *Théorie de la connotation des couleurs*, je propose des mécanismes à l'origine des associations couleurs-émotions. J'explique comment elles sont liées à d'autres constructions (préférences, associations intermodales…) et je suggère comment elles pourraient avoir un impact sur le comportement. Ces études contribuent à combler le fossé entre les connaissances empiriques et les applications pratiques de la couleur.

Extended Abstract

For over 100 years, popular and scientific communities have suggested that colours have psychological and affective implications. We *feel blue* and *see red*; we wear *white* to weddings and *black* to funerals. Such colour-emotion associations are intriguing because colours and emotions seem – at face value – to be fundamentally different "things". Colours are visual experiences driven by the wavelength of light. Emotions are subjective feelings, cognitions, and physiological responses that signal value. Could such arbitrary associations also reflect fundamental aspects of the mind? Or are they symbolic associations, culturally transmitted through our languages and traditions? And, how important are our perceptual realities for colour-emotion associations? In this thesis, and its four empirical chapters, I have systematically assessed universality and stability of colour-emotion associations in different cultures and different perceptual environments to answer these questions.

In all empirical chapters, participants associated 12 colours (presented either as terms or patches) with 20 emotion concepts and rated intensity of the associated emotions, always in their native language. In Chapter 2, we investigated emotion associations with colour terms in 4,598 participants speaking 22 languages and coming from 30 nations, located on all continents but Antarctica. A series of statistical analyses revealed universal patterns in colour-emotion associations, with an average cross-cultural similarity of 88%. But, local differences were also apparent. A machine learning algorithm revealed that nation predicted colour-emotion associations above and beyond those observed universally. Similarity was greater when nations were linguistically or geographically close. This study highlighted robust universal colour-emotion associations, further modulated by linguistic and geographic factors.

In Chapter 3, we emotion associations with colour terms and colour patches in 132 Swiss French-speaking participants to understand whether these associations are stable across colour presentation modes. We again revealed a high degree of similarity in the pattern of colour-emotion associations. Some differences were also apparent. Participants were more likely to associate any emotion with colour terms than patches, and in particular with *black*, and provided different associations for *purple* as a term and as a patch. We concluded that stable

emotion associations are measurable with colour terms and colour patches. These associations are likely to be driven by conceptual mechanisms.

In the following two chapters, I looked at environmental influences on colour-emotion associations, by testing if colour-emotion associations varied with physical environments (climate) or perceptual environments (colour blindness). In Chapter 4, we focused on a prime example – the association of *yellow* with *joy*, – which conceivably arises because *yellow* is reminiscent of life-sustaining sunshine and pleasant weather. *Joy* was the most frequent association with *yellow* across 55 nations and 6,625 participants speaking 40 languages. Yet, consistent with our hypotheses, participants who lived further away from the equator and in rainier countries were more likely to associate *yellow* with *joy*. We did not find associations with seasonal variations. Our findings support a role of physical environments in shaping the affective meaning of colour on top of universally established associations.

In the final empirical chapter, Chapter 5, we compared colour-emotion between colour-blind and non-colour-blind Swiss French-speaking participants (N = 130). Colour-blind and non-colour-blind participants associated similar emotions with colours, irrespective of whether they rated colour terms or colour patches. The degree of colour-blindness was unrelated to the likelihood of colour-emotion associations. Hinting at some additional, although minor, role of actual colour perception, the consistencies in associations for colour terms and patches were higher in non-colour-blind than colour-blind men. Together, these results suggest that colour-emotion associations in adults are stable irrespective of perceptual realities. They do not require immediate perceptual colour experiences, as conceptual experiences are sufficient.

Taken together, these four empirical chapters led to three major conclusions. First, the pattern of colour-emotion associations seems universal across nations, across different colour presentation modes, and different perceptual experiences. Second, these colour-emotion associations are further modulated by perceptual and linguistic experiences. Third, colour-emotion associations have a strong conceptual component, suggesting that these associations are abstract rather than driven by direct visual or affective experience. These studies provide a solid baseline knowledge regarding colour-emotion associations. They also enabled me to make a theoretical suggestion – the Colour Connotation Theory, presented in the discussion. Using

the Colour Connotation Theory, I provide suggestions for the mechanisms driving colour-emotion associations and their universality. I reason how colour-emotion associations are connected with psychological colour meaning more broadly (preferences, cross-modal associations, symbolism) and how colour-emotion associations might lead to colour-related behaviours. I also suggest future direction, such as to further evaluate the universality tenet, study psychological and cognitive mechanisms driving colour-emotion associations or understand within-person stability. More broadly, these studies help bridging the gap between empirical knowledge and practical applications of colour, which are of interest to specialists in design, marketing, communication, and health sectors.

Keywords: colour, emotion, affect, culture, environment, colour perception, colour semantics, basic colour terms (BCT), focal colours, cross-modal correspondences, colour vision deficiencies (CVD), daltonism, dichromatic, trichromatic, cross-cultural psychology.

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Publications During the Doctoral Thesis

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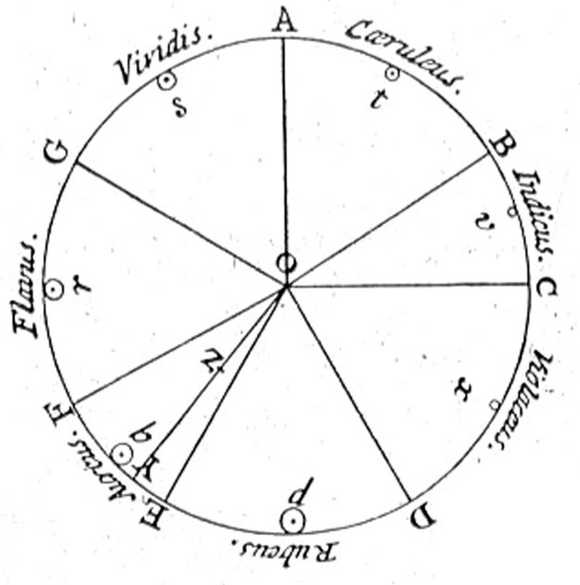
1.

Introduction



"*Colours speak all languages*" – Joseph Addison, English essayist, poet, playwright and politician (1672-1719)

The human mind often makes connections between disparate properties – between sound and shape, between number and space, between odour and pitch. These cross-modal correspondences are assumed to be fundamental to our cognitive architecture, shaped by shared experiences in our evolutionary and individual histories. And yet, such assumptions ignore the large differences between human societies that have been documented through anthropological research, and the established effects of language and culture on cognition. In my thesis, I focus on the seemingly arbitrary association between colour and emotion. We *feel blue* and *see red*; we wear white to weddings and black to funerals. Could such arbitrary associations also reflect fundamental aspects of the mind? Or are they symbolic associations, culturally transmitted through our languages and traditions? And how important are perceptual experiences to these associations?

Both, universality and nation-specificity of colour-emotion associations can be expected. Universality can be expected from the way the affective meaning of colour is communicated to a broader non-specialist audience by the media. Many colour associations and meanings are presented as existing "truths" irrespective of where these associations have been collected (e.g., see https://www.empower-yourself-with-color-psychology.com/meaning-of-colors.html). More precisely, if a media source claims that blue signals *loyalty* and *integrity*, it is assumed that blue signals these ideas everywhere around the world. In contrast, nation-specificity can be expected from the known differences in colour language, colour customs, and colour symbolism between nations. For instance, colour metaphors across languages link colours and emotions differently (e.g., *red*, *black*, or *white* are linked to *anger*; Soriano & Valenzuela, 2009). Brides in China wear *red* and mourners wear *white* in contrast to *white* and *black* worn respectively by brides and mourners in the Western countries. Taken together, common knowledge gives little indication to what extent colour-emotion associations are universal or nation-specific. Yet, these questions should be answered before any advice can be given to the applied domains regarding psychological impact of colours. On the theoretical level, knowledge about universality of the affective meaning of colour provides insight into the cognitive architecture of the human mind.

Universality of colour-emotion associations should be understood in broad terms. High universality would mean that similar colour-emotion associations can be retraced in different cultures and across different conditions. In Chapter 2 (Jonauskaite, Abu-Akel, et al., 2020), I studied whether colour-emotion association patterns were universal across cultures by assessing participants from 30 nations. In Chapter 3 (Jonauskaite, Parraga, et al., 2020), I studied whether colour-emotion associations were stable irrespective of the colour assessment mode (colour term or patch). In the following chapters, I turned to studying environmental and perceptual factors that might further modulate colour-emotion associations. In Chapter 4 (Jonauskaite, Abdel-Khalek, et al., 2019), I assessed the influence of climatological factors on the associations between *yellow* and *joy* in 55 nations. In Chapter 5 (Jonauskaite et al., 2021), I studied colour-emotion associations in colour-blind individuals.

The introduction provides relevant background for the studies reported in the four empirical chapters. I started the introduction by describing what colour is from the physical, physiological, perceptual, linguistic, and conceptual perspectives. I then described colour blindness as a condition affecting all aspects of colour perception and cognition. Then, I turned to describing what emotion is by focusing on emotion description as a separate category (e.g., happy, sad) and as a point on an affective dimension (e.g., valence, arousal). Afterwards, I introduced previous literature on the associations between colours and emotions, by separating the literature into colour associations with affective dimensions and colour associations with specific emotions. Finally, before going on to the empirical chapters, I closed the introduction with some consideration of what universality means from the psychological perspective and how it can be tested.

1.1. What Is Colour?

Everyone knows what colour is, or rather what colour is not. For instance, colour is not *black and white* films or photographs, colour is not night, colour is not the depth of the ocean, and colour is not an empty space in the universe. Thus, it seems that the B&W world is contrasted with else, and that else is colour. From these *what colour is not* examples, it becomes apparent that colour has something to do with light. Or rather, the absence of light results in no colour. However, light alone is not sufficient to "produce" colour because colour perception requires an observer. The knowledge of human physiology is necessary to understand how light becomes colour perception. Once colour is perceived, similar colours can be grouped together to make colour categories in one's mind, categories can be named, and one can communicate about colour using colour terms. Thus, a complete understanding of colour requires colour description from a physical, physiological, perceptual, linguistic, and conceptual points of view.

1.1.1. Physical Colour

From the physical point of view, colour results from properties of visible light. Light is a form of electromagnetic radiation, which consists of waves. These waves are perturbations in the electric and magnetic fields that propagate at the speed of light. The smallest possible perturbation is called a *photon* (a.k.a., a light particle). The physical properties of electromagnetic waves depend on the wavelength. The wavelength can be anywhere between kilometres for radio waves (low energy), used to broadcast music, to picometres for gamma radiation (high energy), which is released in nuclear reactions or high energy cosmic events. Waves with a shorter wavelength, and thus a higher frequency, carry more energy. The part of the electromagnetic spectrum that humans can perceive is called **visible light** and it is composed of wavelengths approximately between **390 and 730 nanometres** (nm; Hecht & Zajac, 2013; Figure 1.1A).

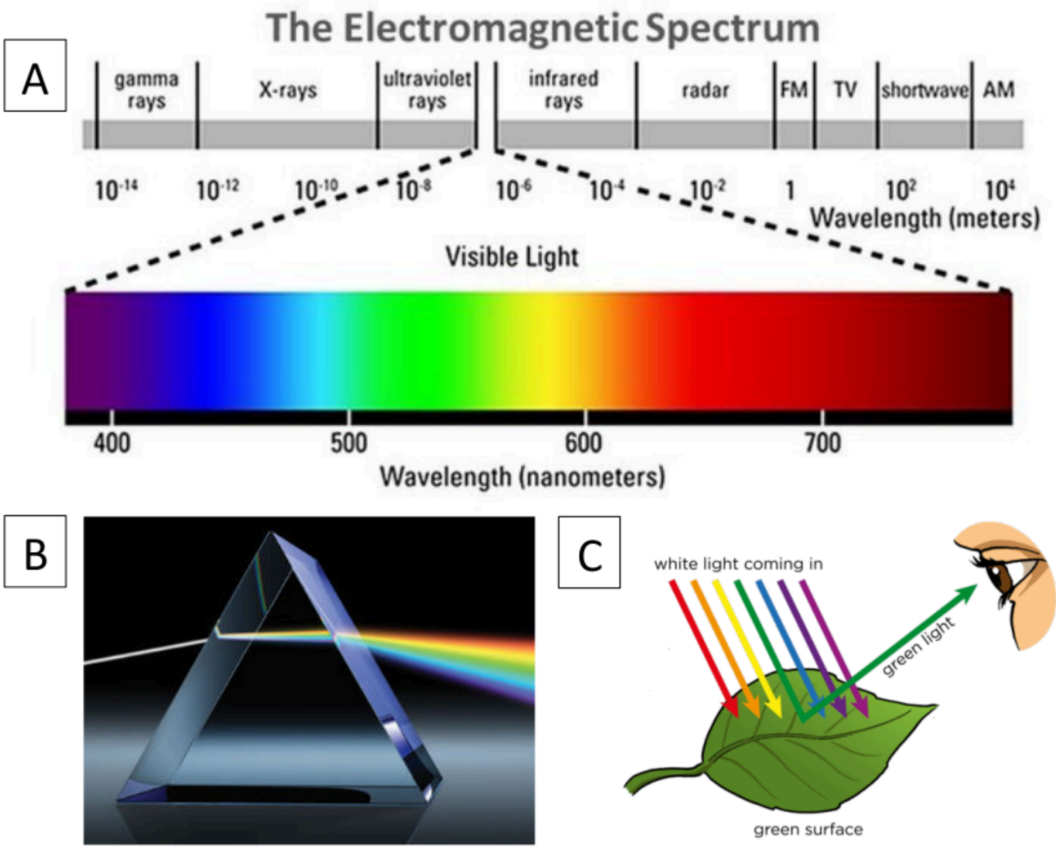


Figure 1.1. The physics of colour.

(A) The visible light is a part of the electromagnetic radiation, with wavelengths between 390 and 730 nm. (B) A glass prism refracting light into different colours. (C) An object (here, a leaf) reflecting wavelengths of around 530 nm (i.e., greenish light) while absorbing the others. To a human observer, the leaf therefore appears green.

Light rarely consists of radiation with a single wavelength. Rather, many different wavelengths can be present in light because light rays of different wavelengths can be superimposed without affecting each other (Hecht & Zajac, 2013). Hot objects, such as the Sun, radiate a continuous spectrum of mainly infrared and visible light (blackbody radiation; Planck & Masius, 1914). Daylight is mainly composed of the blackbody radiation of the Sun and is perceived by humans as white (Hunt & Pointer, 2011b), even though it contains light rays of many different wavelengths. Newton (1704) famously demonstrated how a glass prism breaks the white daylight into a spectrum of light of different colours (Figure 1.1B). The separation of white daylight into the colour spectrum happens because light with different wavelengths is refracted at different angles at the boundary between air and glass. The angle of refraction depends on the speed of light in glass, which is slightly different for different wavelengths – short wavelengths (bluish) are refracted more than long wavelengths (reddish). This phenomenon is known as *dispersion* (Hecht & Zajac, 2013). When the light emerges from the glass prism, it is separated by wavelength, with each wavelength having a slightly different direction. The wavelengths are arranged in fixed order and appear to a human observer as a rainbow, ordered from red to purple (violet).

Objects can selectively reflect some wavelengths of light while absorbing the others (Figure 1.1C). Therefore, the objects appear as being of a colour that corresponds to the reflected wavelengths. Analogously, light sources, such as computer monitors or lasers, can selectively emit certain wavelengths of light and appear as being coloured. In addition to differing with respect to wavelength, reflected or emitted light also differs with respect to power (i.e., the amount of light that arrives at a location in a time unit). The colours that are actually perceived depend on a visual system that decodes the signal. Both wavelength and power information contribute to colour vision.

1.1.2. Physiological Colour

From the physiological/neurological point of view, colour perception requires a dedicated biological mechanism to decode the light signal. Different animals have different visual systems and decode colour in very different ways (Marshall & Arikawa, 2014). For instance, bees do not possess receptors to decode red colours, only blues and greens, so red flowers appear greenish/brownish to them. However, they have an additional photoreceptor of UV light, and can avoid its damaging effects. Butterflies have as many as 12 different colour receptors, and use some of them for very specific behaviours (e.g., laying eggs on the “right” kind of green leaves). Thus, the same wavelength of the visible light may evoke different colour perceptions and lead to different behaviours, depending on the animal species. Two conditions must be fulfilled for a visual system to extract colour information from a scene. First, there must be more than one class of photoreceptors. Second, there must exist some kind of differencing mechanisms to compare the inputs from both classes of receptors (Rushton, 1972). These two conditions are obviously fulfilled in humans (or this thesis could stop here).

The Eye

Colour vision starts with the eye and goes through different stages of visual processing (Stockman & Brainard, 2015). When the light hits an eye, it enters through the cornea and the pupil, before being focused by a lens on the **retina** (Figure 1.2A). The retina, located at the back of the eye, contains three broad classes of light-sensitive cells – *photoreceptors*. The classes of photoreceptors are rods, **cones**, and, the recently discovered, intrinsically photosensitive retinal ganglion cells (ipRGCs). The ipRGCs play a role in controlling the pupil size (Gamlin et al., 2007) and regulating the circadian clock (Berson, 2003). Their contribution to conscious vision is much less clear (Do & Yau, 2010). Rods are highly sensitive to light, and they are responsible for vision in low light conditions (*scotopic* vision). Rods do not contribute to colour vision in humans although their spectral sensitivity is tuned to ~498 nm (see Musilova et al., 2019 in fish). In daylight conditions (*photopic* vision), rods become saturated and provide little information about the environment. Cones, on the contrary, are responsible for vision in typical daylight conditions (*photopic* vision) because they are less sensitive to light than rods. At the intermediate light conditions, at dawn and dusk, both rods and cones contribute to vision (*mesopic* vision; Buck, 2014). As cones are mainly responsible for colour vision, human can see colour only in the hours between dawn and dusk.

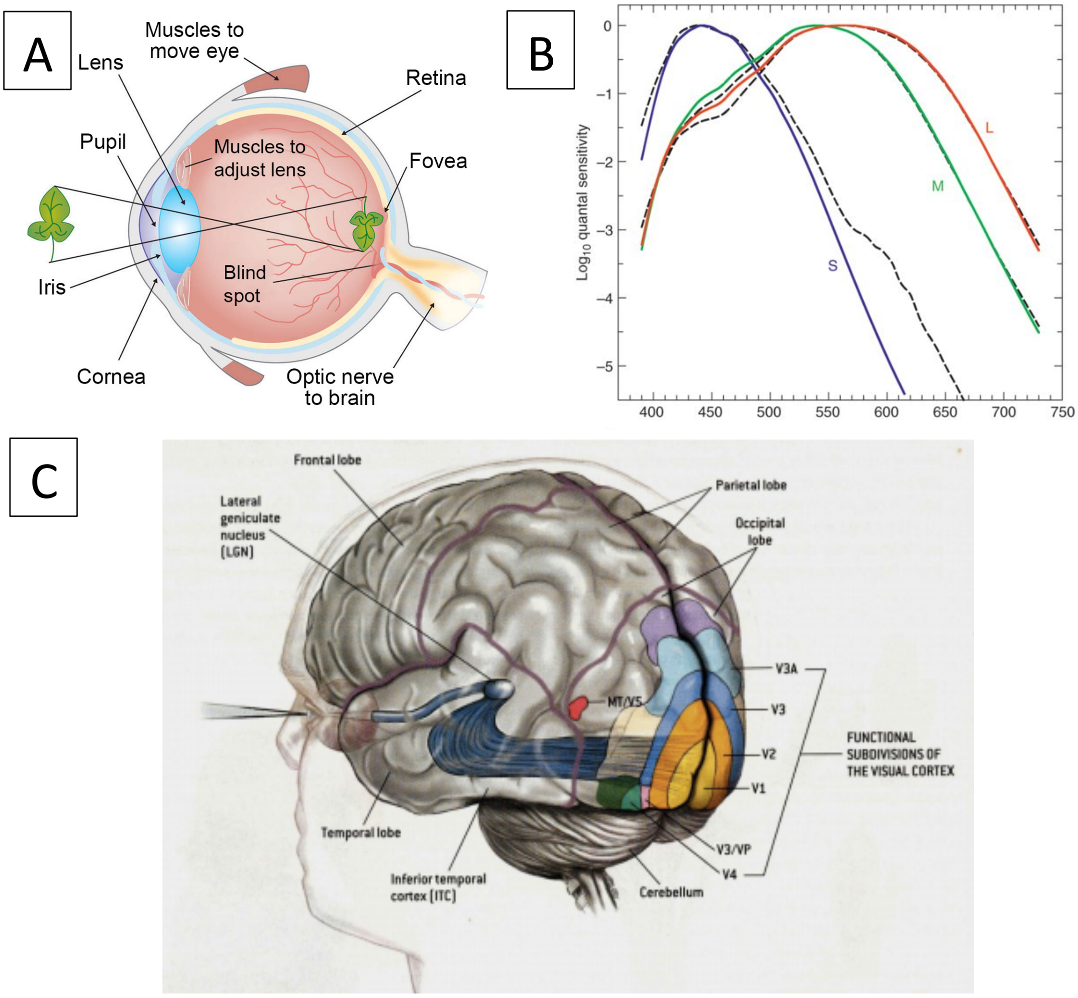


Figure 1.2. The physiological mechanisms underlying human colour vision.

(A) An eye forming an image of a scene at the back of the eye (retina). (B) The distributions of wavelength sensitivity of each class of cones (L-, M-, and S- cones). Wavelength sensitivities measured by Smith and Pokorny (1975) (dashed lines) and Stockman and Sharpe (2000) (solid coloured lines). The figure taken from Stockman and Brainard (2015). (C) The visual pathway from the retina, to the thalamus, and the visual cortex.

Colour vision is possible due to the existence of the three classes of cones, sensitive to different wavelengths. Long (L) wavelength-sensitive cones are mainly sensitive to red light, Medium (M) cones to green light, and Short (S) cones to blue light. The presence of the three classes of cones enables *trichromatic* colour vision. Deficiency or absence of one class of cones leads to *anomalous trichromatic* or *dichromatic* colour vision, respectively. The condition is also known as **colour blindness**, as well as “Daltonism”, named after John Dalton, who was first to describe the condition (Dalton, 1798). The most common form of colour blindness is red-green colour blindness, resulting from defect or complete absence of photopigments coding either L- or M-cones (Parry, 2015). The cones convert an electromagnetic signal (i.e., light) into a neural signal through **opsins**[1]. Opsins are proteins in the **photoreceptors** that absorb *photons* and transmit a neural signal through a cascade of biochemical events, called *phototransduction* (Arshavsky et al., 2002; Burns & Baylor, 2001). Photoreceptors effectively count photons of particular wavelengths. If the wavelength of a photon falls within the **spectral sensitivity** region of a photoreceptor, the photoreceptor can be excited. The probability of a photoreceptor being excited varies within the spectral sensitivity of the photoreceptor and it is highest at its peak. The peak spectral sensitivity of L-cones is approximately at 560 nm, M-cones is ~530 nm, and S-cones is ~430 nm (Stockman & Brainard, 2015). Spectral sensitivities of L- and M-cones are broad and overlapping, covering the entire visible light spectrum. Spectral sensitivity of S-cones is much more restricted, and mainly located in the region of visible light spectrum below 560 nm (see Figure 1.2B). The breath of spectral sensitivities means that any type of light stimulates more than one class of cones.

Colour vision at the retinal level is achieved by comparing input from all three classes of cones. For instance, a wavelength that has a length between the peaks of L- and M-cones (e.g., 545 nm) is perceived as yellow because both L- and M-cones are excited to the same extent. The identical perception of yellow can be achieved by simultaneously stimulating L- and M- cones through shining red (e.g., 560 nm) and green (e.g., 530 nm) lights. This effect arises because the retina sends an identical signal to the brain in both cases. In other words, humans perceive many colours that are physically distinct as identical. Hence, an infinite dimensional colour space at the physical level becomes a three-dimensional colour space at the physiological level.

The comparison of the three classes of cones happens in the subsequently connected retinal cells. The cones (and rods) send neural signals to the bipolar cells, which in turn activate the

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[1] Opsins in the L-, M-, and S-cones are coded with opsin genes – OPN1LW, OPN1MW, and OPN1SW respectively, which provide a genetic basis for colour vision (Nathans et al., 1986).

retinal ganglion cells. The retinal ganglion cells combine the cone signal to enhance signal-to-noise ratio and reduce redundant information. The axons of the retinal ganglion cells form an **optic nerve** and transmit colour information via three channels (Dowling, 1987). The **magnocellular** pathway responds to an overall change in L- and M-cone inputs (i.e., L+M activity) and roughly corresponds to the light-dark variation. The **parvocellular** pathway responds to relative, opposing variations in L- and M-cone inputs (i.e., L-M activity) and roughly corresponds to the red-green variation. Finally, the **koniocellular** pathway responds to relative, opposing variations in the S-cone input compared to the overall input from L- and M-cones together (i.e., S-(M+L) activity) and roughly corresponds to the yellow-blue variation. The three distinct stimulations, specific to the three colour pathways, have been coined as the **cardinal colour directions**. They can be represented as three axes in a three-dimensional space (originally described by MacLeod & Boynton, 1979, adapted by Derrington, Krauskopf, & Lennie, 1984). Every perceived colour corresponds to a point in this three-dimensional space.

The Brain

The cardinal colour direction system is maintained in the higher order neural structures – the **lateral geniculate nucleus (LGN)** and the **visual cortex** (Figure 1.2C). The optic nerve carries neural signals from the retina to the LGN, located in the thalamus[2]. The LGN integrates the information of the three colour channels in its six different layers. The two ventral layers (1 and 2) of the LGN process the magnocellular and the koniocellular pathways while the four dorsal layers (3, 4, 5, and 6) of the LGN process the parvocellular pathway (Casagrande, 1994; Hubel & Wiesel, 1977).

The axons of the LGN further project the neural signal to three distinct regions of the **primary visual cortex** (V1), which is located in the occipital lobe of the cerebral cortex. The

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[2] The optic nerve also transmits colour information to other neural structures, namely, the pretectal nucleus, the superior colliculus and the suprachiasmatic nucleus. They are little if not at all involved in colour vision (but see, Herman & Krauzlis, 2017).

magnocellular pathway innervates in layer 4Cβ, the parvocellular pathway in layer 4Cα, and the koniocellular pathway in layers 4A, 3, and 1 of the V1 (Kandel et al., 2012). In the V1, there are cells that respond to pure colour signals, colour and luminance signals, and pure luminance signals. Some of the colour-selective cortical cells in V1 respond to the cardinal colour directions of the LGN, but many respond to the colour axes that are not cardinal (Cottaris & De Valois, 1998), which enables a finer discrimination of colours.

The next stage of colour processing happens in the secondary visual cortex (V2). It builds a finer-grained representation of colour and contains cells that selectively respond to more specific hues. Beyond V2, the colour information is projected to V3 and V4, both of which are exclusively located in the left hemisphere. V3 contains cells that encode motion and colour signals. The response of V3 to colour is evenly distributed throughout the colour space, which provides further tuning to the colour processing. **V4** contains many cells that selectively respond to colour. For this reason, V4 was once considered as the main module of colour processing (Van Essen & Zeki, 1978; Zeki, 1983). Lesions in V4 produce impairments in colour vision, for instance, achromatopsia – complete colour blindness (Walsh et al., 1993; Zeki, 1990). However, V4 also processes other visual features, like shapes and contours (Pasupathy & Connor, 2002; Yau et al., 2013), so it is unlikely to be solely dedicated to colour processing. V4 feeds to V8 and their function in colour vision is the focus of current ongoing research (Bushnell et al., 2011; Roe et al., 2012). Their function might extend beyond coding for perceived colour and also include imagined colour (Bannert & Bartels, 2018) and synaesthetically-experienced colours when hearing spoken words (Nunn et al., 2002).

Taken together, colour processing starts in the retina, continues in the thalamus and is distributed throughout the visual cortex, becoming more and more selective as the signal proceeds though the visual hierarchy. The final product of colour processing creates a unified perception of colour in one’s mind.

1.1.3. Perceptual Colour

From the **perceptual** point of view, colour is experienced as a unified percept of "blue", "red", "orange", etc., and can mathematically be described using three-dimensional models[3]. Humans are able to perceptually discriminate around 2 million colours (Linhares, Pinto, & Nascimento, 2008; although the exact number is unknown, see Masaoka, Berns, Fairchild, & Moghareh Abed, 2013). Each of these colours can be uniquely described on a three-dimensional space [4]. There are multiple mathematical ways to describe and represent colours on these spaces, formally known as **colour appearance models** and **colour order systems**.

Historically, colour order systems progressed from being one-dimensional, to two-dimensional, to the modern three-dimensional systems (Kuehni & Schwarz, 2008). In 360 B.C.E., Aristotle positioned colours on a linear scale from white to black, with yellow, red, purple, green, and blue in between. This one-dimensional colour order system was prevailing until 17th century (e.g., Avicena, circa 1050; da Vinci, circa 1500; cited in Kuehni & Schwarz, 2008), until the line was closed by making it into a circle (Fludd, 1629; Forsius, 1611; cited in Kuehni & Schwarz, 2008). However, this circle included chromatic as well as achromatic colours; therefore, it cannot be yet considered to be a two-dimensional colour system. It was Newton who first suggested a real two-dimensional colour order system with hues arranged in a circle (Newton, 1704). Newton divided the circle into seven colours – violet, red, orange, yellow, green, blue, and indigo, – in analogy to the seven musical notes. Newton's colour circle inspired subsequent

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[3] While mathematical descriptions are objective for a "standard observer" (i.e., aggregated data drawn from psychophysics discrimination experiments of human informants), there are also subjective questions such as *What does blue look to an observer?* and more generally, *What is colour? Do all people see colour in the same way? Does your "blue" look "red" to me?* and so on. These and similar questions enter philosophical realm of discussion and have no single answer (Dedrick, 2015).

[4] The reason why colour is perceived as a three-dimensional and not as a four-, five-, or two-dimensional object is the existence of three classes of cones.

two-dimensional representations of colour, some of which are still used by artists and designers today (Boutet, 1708; Chevreul, 1855; Goethe, 1810; Hayter, 1826; Itten, 1961). The two-dimensional models emphasised how primary colours should be mixed together to give rise to all other colours. Although useful for artists, these models are incomplete from the perceptual point of view. The latter must be described with three-dimensional colour order systems, like the ones used today (e.g., Munsell Colour Order System, *CIE Lab*, *CIE Lch*, Natural Colour System, Ostwald Colour System, etc.).

The three-dimensional colour order systems describe colours in comparable ways. For example, the *CIE* (*Commission internationale de l'éclairage*) *Lch* system and the *Munsell Colour System* (Munsell, 1912) describe colour in terms of three colour attributes: **hue**, **lightness (value)**, and **chroma** (Figure 1.3A; Fairchild, 2015; Hunt & Pointer, 2011a). *Hue* is what laypeople refer to as colour (e.g., red, blue, orange, etc.) and is considered to appear as a closed ring (i.e., from red to yellow, green, blue, purple, and again red). *Lightness*, referred to as value in the Munsell system, describes how light or dark a colour is. Formally, lightness is defined as brightness of an area judged relative to the brightness of the *reference white* – another area of the same brightness which appears white[5]. Finally, *chroma* describes how pure or greyish a colour is in proportion to the brightness of a similarly illuminated white area. Colours low in chroma appear greyish – *achromatic*[6].

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[5] *Brightness* is a related term to lightness but describes an absolute measure of how much an area appears to emit or reflect light. Lightness and brightness should not be confused with each other and with related terms like *luminance* and *reflectance,* which describe physical rather than perceptual properties of colour (Fairchild, 2015).

[6] Chroma should not be confused with related terms such as *colourfulness* (i.e., appearance of an area as more or less chromatic; ranging from dark to pure chromatic colours) and *saturation* (i.e., colourfulness judged in proportion of brightness; ranging from light to fully saturated chromatic colours) (Fairchild, 2015).

The three colour attributes (i.e., hue, chroma, and lightness) are inter-dependent. For example, the most chromatic *yellow* (e.g., Munsell hue = 2.5Y; Figure 1.3B) is high in chroma (Munsell chroma = 16) and it is also relatively light (Munsell value = 8). In contrast, the most chromatic *blue* (e.g., Munsell hue = 5B) is much lower in chroma (Munsell chroma = 10) and darker (Munsell chroma = 4-6). This inter-dependence of colour attributes poses serious problems to psychologists trying to assess the independent contributions of hue, chroma, and lightness to human psychological functioning (see later sections).

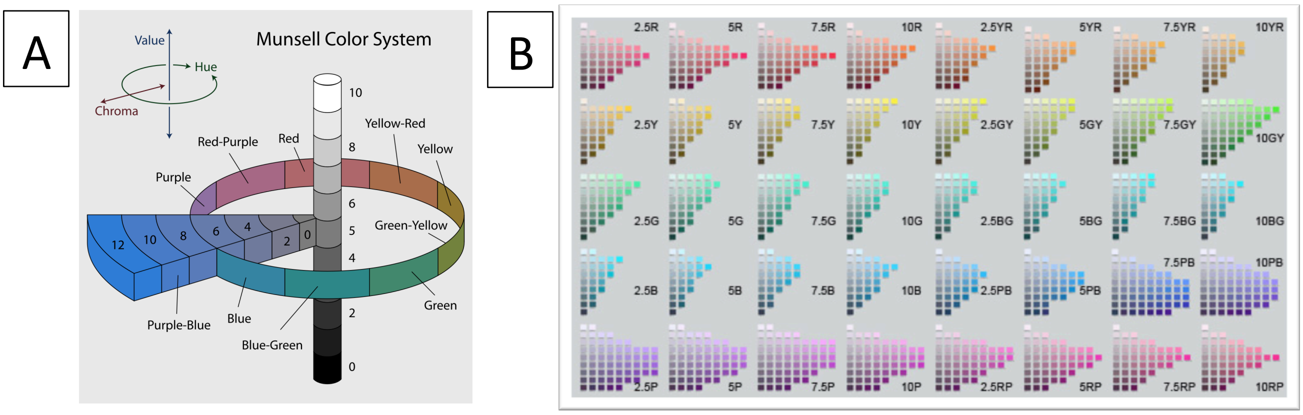

Figure 1.3. Colour appearance from a perceptual point of view – the Munsell Colour Order System.

(A) Three colour attributes (dimensions) according to the Munsell system: hue, chroma, and value (lightness). (B) Value and chroma values for different hues, ordered from red (2.5R) on the top left corner to red-purple (10RP) on the bottom right corner. Note how perceptually possible value (lightness) and chroma values are inter-dependent with hue (Munsell, 1912).

1.1.4. Linguistic Colour

"*More distinctions of colour are detected by the eye than are expressed by words and terms. For leaving out of account other incongruities, your simple colours, red (rufus) and green (viridis), have single names, but many different shades.*" From "Attic Nights" by Aulus Gellius [7].

From the **linguistic** point of view, colour is understood as a linguistic referent (i.e., **colour term**), which is used to name perceived colours. The existence of colour terms stems from the need to communicate about colour, especially for objects which differ only in their colour/hue (Wierzbicka, 2015). For instance, ripe berries look a lot like unripe berries expect that they are red. This need for communication is intensified in industrialised societies where plenty objects differ only in their colour/hue (just think about a large selection of t-shirts in a supermarket). Put differently, less industrialised societies have a lower need to communicate about colour and so have fewer colour terms.

Following the long-standing tradition, colour terms are separated into the **basic colour terms** and the non-basic colour terms (Berlin & Kay, 1969; Kay, Berlin, Maffi, Merrifield, & Cook, 2009)[8]. The basic colour terms should be known to all adult native speakers and are frequently

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[7] A. Gellius wrote about the Discourses of Marcus Fronto and the philosopher Favorinus on the varieties of colours and their Greek and Latin names. For the English translation, see (Rolfe, 1862).

[8] While intuitively a separation between the basic colour terms and non-basic colour terms appears simple (i.e., *red* feels more "basic" than *scarlet*), there are questionable cases (Lindsey & Brown, 2014; Morgan, 1993; Witzel, 2019). In their seminal work, Berlin and Kay (1969) proposed four primary and four secondary criteria to identify basic colour terms. The basic colour terms should be *monolexemic*. The meaning of the basic colour terms should not be totally contained in the meaning of another word (*hyponymy*). The basic colour terms should not be contextually restricted (*context independence*). They should also be used with high *consistency* by each speaker and high *consensus* across speakers. Secondary criteria of basic colour terms are used only when primary criteria cannot unambiguously identify a basic colour term. Secondary criteria exclude recent foreign loan words, colour terms that

used in a language (Biggam, 2012b). English, French, and many other modern Indo-European languages, have 11 basic colour terms, namely *red, orange, yellow, green, blue, purple, pink, brown, grey, white,* and *black.* Most basic colour terms refer to hue (e.g., *red*, *orange*, *yellow*) but some also qualify lightness (e.g., *pink* is light red, *brown* is dark yellow or orange) or chroma (e.g., *grey*).

The **non-basic colour terms** are less known to adult native speakers. They give precision to colour descriptions and take many different forms. For instance, they can be created by a qualifier to a basic colour term (e.g., *sky blue, dark green, off-white*), using a specialised word (e.g., *burgundy, khaki, magenta, turquoise*), or creating an entire phrase (e.g., *dead leaf colour;* Biggam, 2012c). Some non-basic colour terms are used only in specific contexts by specialists (e.g., *Prussian blue* used mainly for pigments; Eastaugh, Walsh, Chaplin, & Siddall, 2004). Overall, non-basic colour terms may carry connotations above and beyond the reference to an actual colour (see an example of *crimson* in Tolochin & Tkalich, 2018).

The number of non-basic colour terms has rapidly increased since 19th century with the invention of new dying technologies (Casson, 1994) and this number varies between speakers of the same language, depending on their profession and interests. Non-specialist native speakers know around 27-30 colour terms (Derefeldt & Swartling, 1995; Griffin & Mylonas, 2019) but this number can reach 70 or more colour terms (Uusküla et al., 2012). If we consider the total number of non-basic colour terms in a language, and not only the terms known by a single speaker, this number can reach 10,000 words, as it is the case in Hungarian (7,097 non-basic terms, Uusküla et al., 2012). In English, Wikipedia lists around 1,500 distinct colour terms (https://en.wikipedia.org/wiki/List_of_colors_(compact)). Examples include *amaranth*, *cobalt*

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correspond to object names (*homonymy*), and comparatively long expressions. Recently, it has been suggested that “basicness” should be seen as a continuum rather than a hard separation into basic and non-basic colour terms (Mylonas & MacDonald, 2015; Witzel, 2019). Thus, several colour terms like *turquoise*, *lilac* or *peach* could be considered as “emerging” basic colour terms in American and British English (Lindsey & Brown, 2014; Mylonas & MacDonald, 2015).

blue, *queen pink*, and *eggshell*, as well as more rare terms like *catawba*, *gamboge,* and *zaffre*. The Internet-famous blogger xkcd reported 954 most common distinct colour terms following his online survey of 222,500 people (https://blog.xkcd.com/2010/05/03/color-survey-results/). Examples include *seafoam green*, *robin's egg blue*, *macaroni and cheese*, and *bubblegum pink,* as well as less tasteful *ugly green*, *sickly green*, and *poop*. Many of the colour terms appear in only one of the two lists. Hence, it is extremely difficult to estimate the number of distinct non-basic colour terms in English.

1.1.5. Conceptual Colour

From the **conceptual** point of view, the myriad of colour perceptions can be grouped into **colour categories** (concepts) and denoted using **colour terms**. While colour perception is continuous, colour categories are discrete, just like colour terms (Figure 1.4.A & B). The principal colour categories coincide with the basic colour terms (Biggam, 2012a) but colour terms differ from colour categories in some important ways. Colour terms deal with the *form* of the word while colour concepts/categories deal with the *meaning* of the word. A bilingual English-French speaker might have a concept of green, which they can refer to by *green* in English and *vert* in French. At the same time, two words written in the same way might have different meanings. Biggam (2012a) gives an example of Middle English *rēd,* which had a broader meaning than modern English *red* and was used to refer to pink or purple as well as red. Furthermore, colour terms are not randomly distributed over the colour space but fall within specific areas (Kay & Regier, 2003; Lindsey & Brown, 2006). The best examples of colour terms, also called the **focal colours**, have been shown to cluster together across 110 *World Color Survey* languages (Regier et al., 2005).

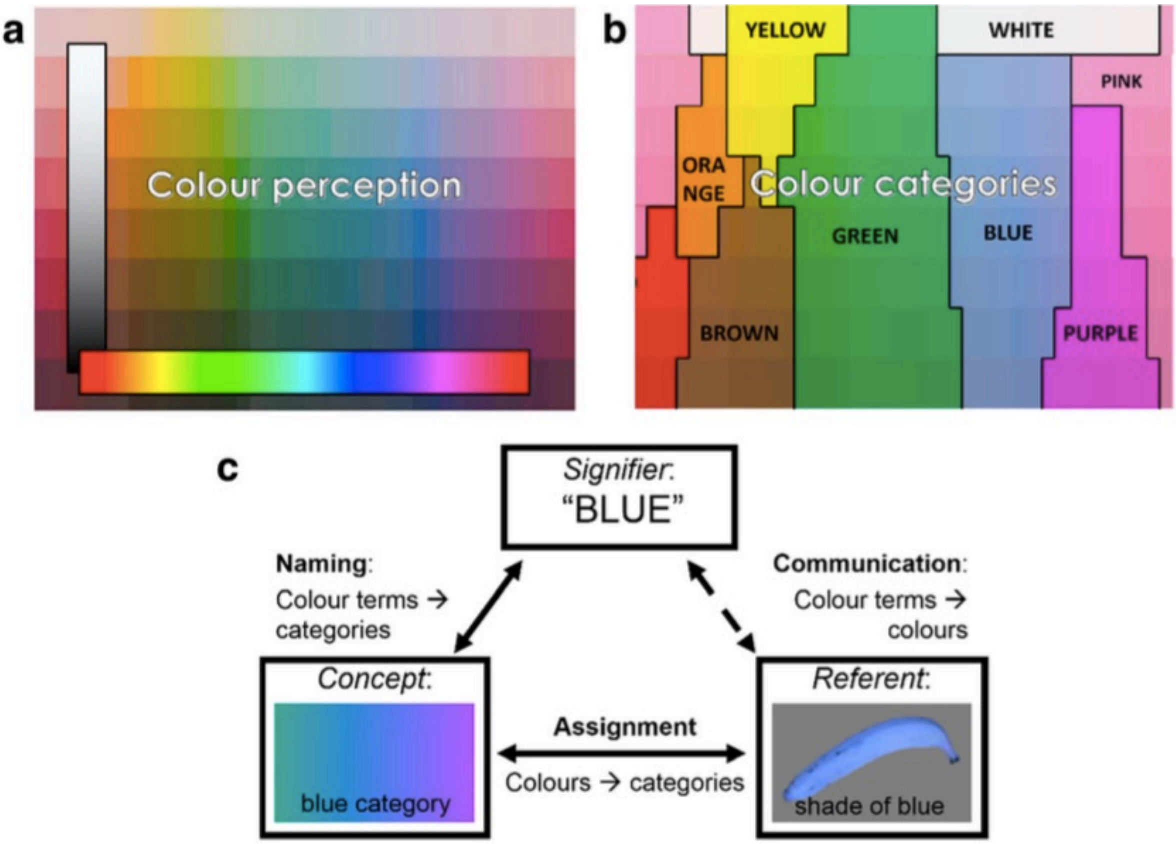

Figure 1.4. The relationship between colour perception and colour categorisation.

(A) The continuous spectrum of perceived colours. (B) Categorisation of the perceived colours into abstract colour categories. (C) The relationship between colour concept (here, blue category), colour term (here, signifier blue), and the object in that colour (here, blue banana). The figure was taken from (Witzel, 2019).

1.1.6. Colour as a Whole

When all aspects of colour are taken into account, **colour can be defined as a three-dimensional perceptual experience, arising from a complex treatment of light in the visual system, which is categorised into discrete conceptual colour categories and semantically labelled with colour terms.**

Colour perception, colour naming, and colour knowledge are importantly inter-connected in one's mind. The classic Stroop effect (Stroop, 1935) demonstrates how naming the ink of letters is hampered when letters compose an inconsistent colour term (e.g., naming blue ink of the word *yellow*). Similarly, auditory presentation of task-unrelated colour terms interfered with discrimination performance of colour patches (Richter & Zwaan, 2009). Priming studies demonstrated that i) colour perception automatically activates a semantic network connected to its colour name (e.g., seeing red primes TOMATO; Nijboer, Van Zandvoort, & De Haan, 2006), and ii) semantically unrelated prime-target pairs are related when concepts are of similar colours (e.g., RUBY primes APPLE; Yee, Ahmed, & Thompson-Schill, 2012).

Colour perception, colour naming and colour knowledge are also inter-connected in the brain. Neuroimaging studies provide evidence regarding the shared neural networks of colour perception and colour knowledge in the left **fusiform** (W. K. Simmons et al., 2007; Slotnick, 2009) and left **lingual** (Hsu et al., 2012) **gyri**. Regions near the fusiform gyrus have been previously implicated in the later processing stages of colour perception (Clark et al., 1997; Hadjikhani et al., 1998; Zeki et al., 1991) as well as other cognitive functions, including recognitions of human faces and bodies (McCarthy et al., 1997; Peelen & Downing, 2005) and reading (McCandliss et al., 2003).

Despite being inter-connected, these functions are not identical. At least partly separated neural networks must be underlying these functions as demonstrated by distinct neuropsychological conditions: i) **colour anomia**, which is characterised by an inability to name visually presented colours (Davidoff & Ostergaard, 1984); ii) **colour agnosia**, which is characterised by an inability to recognise colours despite no known perceptual impairments (Davidoff, 1996); and iii) cerebral **achromatopsia**, which is a complete colour blindness following cortical damage with no impairments in conceptual understanding of colour (Zeki, 1990).

Together, these studies provide some evidence in favour of the embodied cognition theory (Barsalou, 1999, 2008; Barsalou et al., 2003; Rizzolatti & Craighero, 2004). According to this theory, conceptual representations of knowledge are grounded in the neural mechanisms underpinning the actions in the real world. For instance, thinking about a particular action, like combing your hair, activates the relevant areas in the motor cortex, related to the hand and arm movements – the mirror neurons (di Pellegrino et al., 1992; Iacoboni et al., 1999). In the case of colour, the neural mechanisms underpinning the actions of seeing and perceiving colour seem to be also implicated (at least partly) in the conceptual processing of colour.

1.1.7. Colour Blindness

So far, colour perception and colour cognition have been described from the perspective of an intact colour vision. However, there are neurological conditions affecting colour vision, like protanopia, deuteranopia, tritanopia, and achromatopsia (Deeb, 2005; Heywood & Kentridge, 2003; Simunovic, 2016; Werner, 2016; Zeki, 1990). Such conditions are interesting from a theoretical point of view because they dissociate colour perception from colour cognition. This dissociation allows testing for mechanisms driving, for instance, colour-emotion associations. In my thesis, I focus on congenital red-green colour blindness, which includes protanopia (or protanomaly) and deuteranopia (or deuteranomaly).

Congenital red-green colour blindness results from a modification in the photopigments of the cone receptors coding for long or medium wavelengths (Parry, 2015, Figure 1.2B & Figure 1.5). Red-green colour blindness is much more common in men, affecting between 6-8% of men in a general population, than women, affecting between 0.4-0.7% of women in the European-Caucasian population (Birch, 2012; Sharpe et al., 1999). This is because red-green colour blindness is an autosomal genetic disorder, carried on the genes located on the X chromosome. About 16% of women are carriers of red-green colour blindness (Deeb, 2005). Typically, they do not have impairment in colour vision. However, they might experience a rare condition of tetrachromacy. Tetrachromats have four types of cones but the spectral sensitivity of the fourth type of cone is often very close to the L- or the M- cones (Deeb, 2005). Therefore, there is little evidence these women actually possess a four-dimensional colour space and the added advantage to colour discrimination is limited (Jordan et al., 2010).

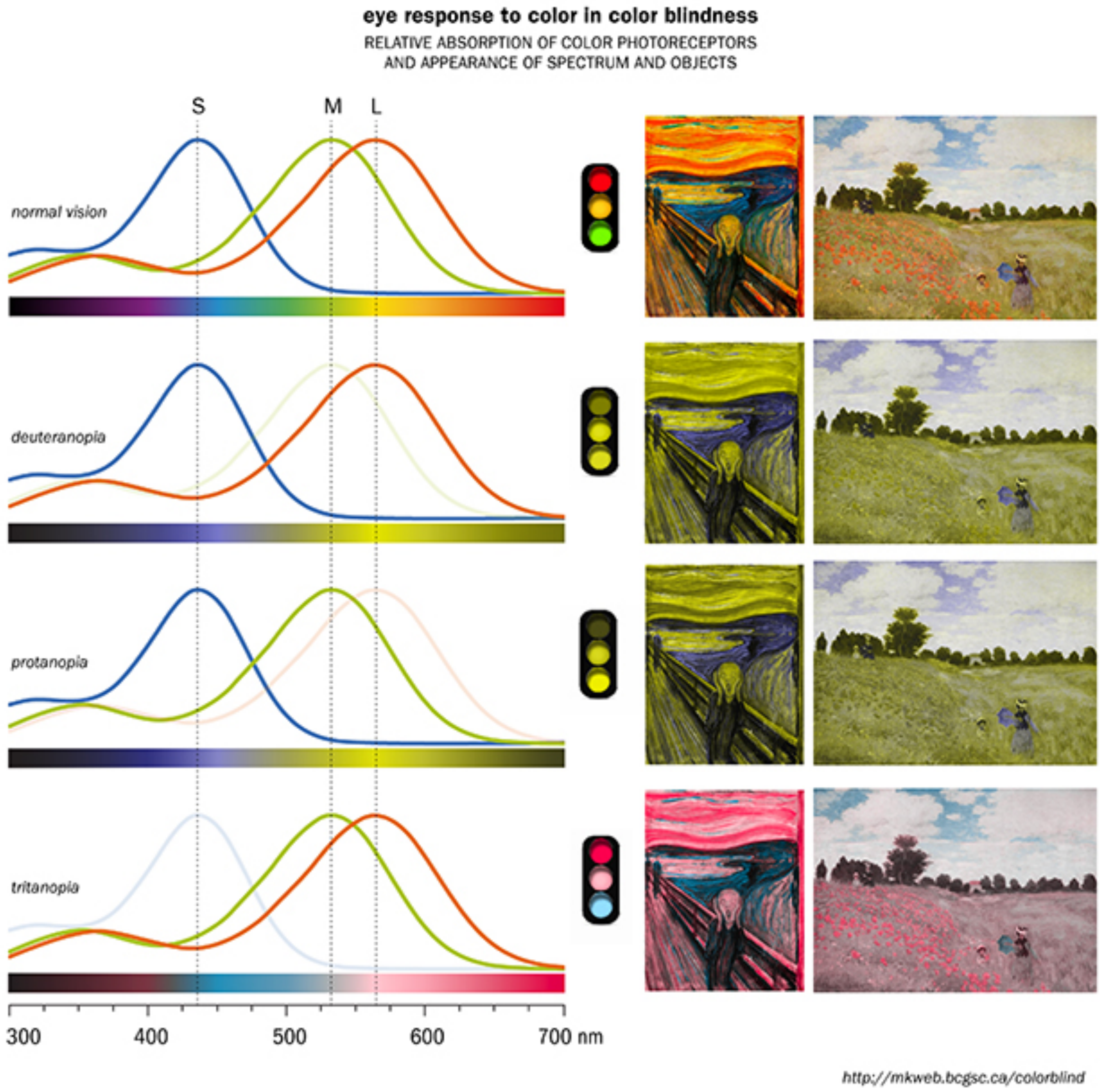

Figure 1.5. Colour blindness: neural underpinnings and perceptual experience.

Left panel displays spectral sensitivities of L-, M-, and S-cones in normal vision (top row), deuteranopia (second row), protanopia (third row), and tritanopia (bottom row). Right panels display a simulation of how the world could look like to people with deuteranopia, protanopia, or tritanopia by using the examples of the traffic light, Edward Munch's "The Scream of Nature", and Claude Monet's "Poppy Field".

Severity of colour blindness varies between individuals. For some individuals, one class of cones can be completely missing. If L-cones are missing, these individuals are said to have *protanopia*, and if M-cones are missing, they have *deuteranopia* (Figure 1.5). Such individuals possess a dichromatic colour vision. For other individuals, all three types of cones are present but one type is malfunctioning due to the change in the photopigment's spectral sensitivities. Again, if L-cones are malfunctioning, such individuals have *protanomaly*, and if M-cones are malfunctioning, they have *deuteranomaly*. Such individuals possess anomalous trichromatic vision. Around 70% of individuals with colour blindness (i.e., 6% of males in a general population) have a form of deuteranomaly or deuteranopia (Simunovic, 2016). In both cases, colour-blind individuals confuse certain colours along the red-green axis and may see the world in bluish-yellowish colours (Byrne & Hilbert, 2010), Figure 1.5). A recent study showed that two colours pairs are particularly difficult to separate – brown-green and purple-blue (Moreira et al., 2021).

Despite perceptual confusions, red-green colour-blind individuals perform relatively well on colour naming tasks (Bonnardel, 2006; Jameson & Hurvich, 1978; Moreira et al., 2014; Nagy et al., 2014). Bonnardel (2006) reported the highest consensus between colour-blind and non-colour-blind individuals' responses in the constrained naming task (74%) as compared to the constrained sorting (68%) and free-sorting (52%) tasks. In the constrained naming task, individuals were presented with 140 Munsell chips, one at a time. They had to name these chips using one of the eight basic colour terms for chromatic colours (i.e., *red, orange, yellow, green, blue, purple, pink,* or *brown*). In both sorting tasks, individuals saw the same Munsell chips and had to sort them by similarity. In the constrained sorting task, they sorted all the chips to eight basic colour categories while in the free sorting task, they could use as many colour categories as they pleased without having to name them. The fact that the highest consensus was achieved in the constrained naming task should not be surprising. This task directly engaged language and language moulds one's understanding of a perceptual continuum of colour into communicable colour categories (Witzel, 2019). If colour-blind individuals name colours similarly to non-colour-blind individuals, they should also possess similar mental spaces of colour.

Indeed, mental spaces of colour are similar when colour-blind individual arrange colour terms. When they arrange colour patches, these spaces look different from non-colour-blind individuals (Saysani et al., 2018b; Shepard & Cooper, 1992). More specifically, non-colour-blind individuals mentally arrange colour terms in a circle organised along the two dimensions (red-green and yellow-blue), and there is an additional dimension of white-black (lightness). Colour-blind individuals arrange colour patches along two dimensions only – white-black and yellow-blue. The collapse of the red-green colour dimension in colour patches is expected from the biological and behavioural expressions of the red-green colour blindness.

1.2. What Is Emotion?

Emotion is notoriously difficult to define. In 1984, Fehr and Russell wrote, “Everyone knows what an emotion is, until asked to give a definition. Then, it seems, no one knows” (Fehr & Russell, 1984). Three years earlier, Kleinginna and Kleinginna (Kleinginna & Kleinginna, 1981) had already highlighted this problem in emotion research. After reviewing 101 texts by different authors, they isolated 92 definitions of emotion. Agreement is still lacking on how to define emotions (Mulligan & Scherer, 2012).

This problem of emotion definition arises because lay understanding of emotion is much boarder and fuzzier than it is useful for research. For laypeople, emotion is anything to do with *feelings*. We feel an emotion when falling in love, being stressed during revisions for an important exam, or spotting a spider on the wall. We can also be considered to be an emotional or an unemotional person, and be described as impulsive, social or extraverted. The layperson might also call it an emotion when a person is generally negative and wary, and also when people love or hate certain food, music or colours. For many researchers, however, these examples do not always represent emotions. Instead, contemporary researchers separately define emotions and additional affective phenomena such as moods, preferences, affective dispositions, or interpersonal attitudes. When talking about these affective phenomena together, it is common to group them under the superordinate term of **affect** (Davidson et al., 2003; Scherer, 2005).

Contemporary researchers define and differentiate emotion from affect in terms of components of these experiences (Scherer, 1982, 2005). For instance, emotion is **“a brief phenomenon, rapidly triggered by an event that generates a coherent response of several components”** (Sander, 2013). Here, the feeling aspect is only one of the emotion components. Accordingly, an emotional experience involves a situational trigger that provokes an emotional experience. In addition to feelings, the experience likely results in a cognitive evaluation of the situation (*appraisal*), and mobilises specific facial, vocal, and bodily expressions. Depending on the emotion, the person might experience changes in their *physiological response* (e.g., sweaty palms, bumping heart, etc.) and *behavioural tendencies* (e.g., approach, avoid). Only relevant situations would trigger emotions. When an emotion is triggered, one’s body and mind react to this emotion in synchrony (*response synchronisation*). People change their behaviour in the face of emotions to respond to the situation that caused the emotion (*behavioural responses*). Nonetheless, emotions change rapidly as one adapts to the new information and re-evaluates the situation (*rapidity of changes*). Hence, emotions are intense (*intensity*) but relatively short-lasting (*duration*).

These components can be exemplified with a person who is afraid of dogs. Seeing a dog on the street would trigger a fear response in this person. The fear response would arise because this person evaluates (appraises) the situation as relevant and threatening. The subjective feeling of fear would be accompanied by sweating, a faster heartbeat, and other physiological symptoms. This person might display a fearful face and have a strong intention to run away, or actually does run away. A person who is not afraid of dogs would not evaluate the situation as relevant and threatening. This person might actually like dogs and experience joy. The subjective feeling of joy might be accompanied by a faster heartbeat. This person might display a smiling face, and have the intention to approach the dog to stroke it. Therefore, people facing the same situation can experience different emotions, or experience no emotion at all, depending on their subjective appraisal of the situation.

1.2.1. Emotion as a Specific Concept: Basic Emotion Theories

Emotions can be studied as specific concepts – *fear*, *joy*, *love*, etc. Often, some of these emotions are also called "basic", the key idea being that basic emotions represent a limited number qualitatively different, hard-wired, and universal emotion processes. The approach stems from Charles Darwin's (1872) work on emotions in humans and animals and dominated emotion research in the 20th century (Ekman, 1992b, 1992a; Ekman et al., 1969, 1987; Ekman & Cordaro, 2011; Ekman & Oster, 1979; Izard, 1977, 1991, 2007; Panksepp, 1982; Panksepp & Watt, 2011; Tomkins, 1962; Tomkins & McCarter, 1964), for a review see, (Tracy & Randles, 2011). In the best known theory, Paul Ekman postulated the existence of seven basic emotions: *happiness, sadness, surprise, contempt, fear, anger,* and *disgust* (Ekman & Friesen, 1971; Scherer et al., 2001). More recently, he identified another 10 emotions (e.g., *relief*, *wonder*, *ecstasy*), which may be added to the basic emotion list if enough evidence for their basicness is gathered (Ekman & Cordaro, 2011). In contrast, other researchers seemed to agree on a smaller number of basic emotions. Jack and colleagues (2016) revealed four latent clusters of facial expressions, roughly mapping on *happiness*, *anxiety*/*fear*/*sadness*, *surprise*/*fear*, and *disgust*/*anger*. Researchers working with linguistic data consistently revealed four stable clusters of emotion concepts – *joy, anger, sadness,* and *fear* (Fontaine et al., 2002; Shaver et al., 1987, 1992; Storm & Storm, 1987). One might conclude that at least four universal clusters exist in emotion meaning. Obviously, there are many more words to describe emotional experience (e.g., Shaver et al., 1987 submitted 135 emotion terms to cluster analysis) but most of these terms would not be considered "basic" [9].

1.2.2. Emotion as a Point on an Affective Dimension: Dimensional Theories

Emotions can also be described along the continua of **affective dimensions.** Already in Ancient Greece, Aristotle considered *hedonic tone*, ranging from very positive to very negative, an important characteristic of emotion (Fortenbaugh, 1975). The dimensional approach of emotion in psychology was pioneered by Wilhelm Wundt (1904), who proposed to organise subjective feelings in terms of positive-negative, calm-excited, tense-relaxed. Other researchers, mainly working on emotional experiences, organised emotions along two dimensions: valence/pleasantness and arousal/activation (R. J. Larsen & Diener, 1992; Russell, 1980; Watson et al., 1988; Watson & Tellegen, 1985). In contrasts, researchers working with

[9] Whether any emotion could be considered "basic" has been a matter of debate within the affective science community for decades. Despite strong proponents of the basic emotion theory (for reviews, see Ekman, 1992a; Levenson, 2011; Panksepp & Watt, 2011; Tracy & Randles, 2011), the theory has received increasingly powerful critiques over the last 40 years (Barrett, 2006; Crivelli & Fridlund, 2019; Ortony & Turner, 1990; Russell, 2003). Perhaps, one source of disagreement about the usefulness of this theory is the definition of "basicness". Philosophers Scarantino and Griffiths (2011) reviewed three senses of "basicness" and concluded that emotions could be considered basic on some but not all senses of "basicness" (see Ortony & Turner, 1990 for senses of "basicness").

semantic meaning of emotion terms consistently uncovered three affective dimensions – **valence, arousal, and power** (Fontaine et al., 2002; Osgood et al., 1957; Shaver et al., 1987, 1992). The fourth dimension (novelty) has also been suggested (Fontaine et al., 2007; Gillioz et al., 2016).

Valence, also called *evaluation*, *hedonic tone*, *pleasantness* or *pleasure*, describes the degree to which an object or an event is considered positive/negative, or an affective response is pleasant/unpleasant (Itkes & Kron, 2019). Examples of positive emotions include *joy*, *pride*, and *relief*, and negative emotions include *anger*, *contempt*, and *disappointment* (see Figure 1.6). **Arousal**, also called *activation*, describes the degree of excitation, often ranging from *calm* to *excited*. To refer to the same emotions, arousing emotions would be *joy* and *anger* while low arousing emotions would be *contempt*, *pride*, *disappointment*, and *relief* (Figure 1.6). Please note, arousal and valence are somewhat independent dimensions; positive as well as negative emotions can be more or less arousing. Finally, **power**, also called *potency*, *control*, or *dominance*, describes one's judgement of having control over a situation. For instance, a person might feel empowered by an experience and wants to do something about or with the experience. Else, a person might feel unable to take control or action. Again, using above emotions, empowering emotions would be *joy*, *anger*, *contempt*, and *pride*, while disempowering emotions would be *disappointment* and *relief* (Figure 1.6). It is important to add the dimension of power since several different emotions are neighbours on the valence x arousal space (e.g., *anger* and *joy*).

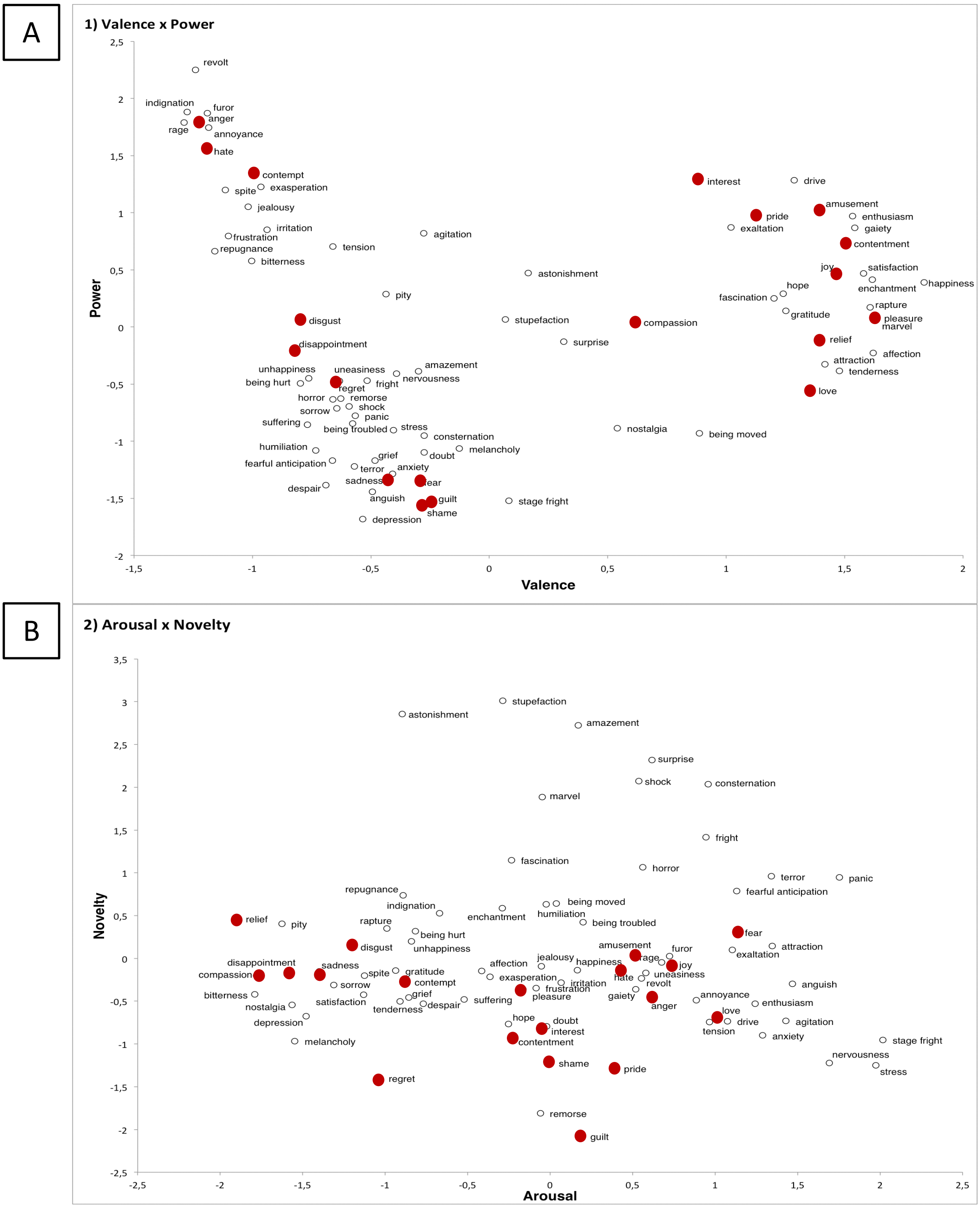

Figure 1.6. Emotions positioned in two-dimensional spaces: valence x power, arousal x novelty.

(A) Emotions positioned on Valence x Power space. (B) Emotions positioned on Arousal x Novelty space. These positions were obtained with the GRID instrument (Fontaine et al., 2013a) in French speakers in Switzerland (Gillioz et al., 2016). In red, emotions used in the current studies on the Geneva Emotion Wheel (*admiration* is missing). Figures adapted from (Gillioz et al., 2016).

1.2.3. Measuring Emotion: Which Approach Is the Best?

When using the *specific emotion approach*, researchers often present their participants with a list of emotion terms. They ask participants either to i) choose the terms that best describe their current feeling (nominal scale) or ii) indicate on a Likert-type scale whether the named emotion was experienced “a little”, “somewhat”, or “strongly” (ordinal scale), or iii) use an analogue scale (e.g., from 0 to 100) to indicate to what extent or how intense the given emotion was experienced (interval scale). Depending on the method, participants are asked to choose one, two, or several emotion terms, or even rate the entire list of emotion terms.

The advantage of this method is its reliance on a natural language, which makes it easy to translate the findings to laypeople because laypeople talk about their emotions using specific labels (e.g “I feel sad, I am nervous, I am in love”). The disadvantage of this method is a lack of a standardised list of specific emotions despite several attempts to establish such a list (e.g., the Differential Emotion Scale, Izard, 1991). Thus, researchers tend to create ad-hoc lists of emotion categories they think are pertinent to their current research studies. Such choices make it difficult if not impossible to compare findings across studies (J. T. Larsen et al., 2009; Scherer & Ceschi, 2000). Further difficulties arise because some emotion terms are more common than others, and because people may interpret their meanings differently (i.e., adhere to different definitions).

When using the *dimensional approach*, researchers often ask participants to report how positive/negative, or excited/calm they are feeling or to rate a particular concept on these dimensions (e.g., Bradley & Lang, 1994; Milin & Zdravković, 2013; Osgood et al., 1957; Warriner et al., 2013; Watson et al., 1988). Since responses can be easily located on a two (or three) dimensional space, such data allows for a simple and reliable statistical processing. However, the information obtained with these methods is limited so lay people do not naturally express their emotions as a point in an affective space. For example, there is little meaning in saying “I feel 2.6 positive and 1.4 aroused”. Therefore, it might be worth combining the two approaches together to obtain the most accurate assessment of emotion.

The Geneva Emotion Wheel

The Geneva Emotion Wheel (GEW, Figure 1.7, Scherer, 2005; Scherer et al., 2013; Tran & Scherer, 2004) combines the specific emotion approach with a dimensional approach with a goal to create an intuitive and user-friendly tool to measure emotions. The GEW has been used in variety of settings (Li & Mao, 2012; Pammi et al., 2009; Sacharin et al., 2012; Siegert et al., 2011; Tschan et al., 2010). Throughout this thesis, the GEW will be used as a tool to measure conceptual colour-emotion associations.

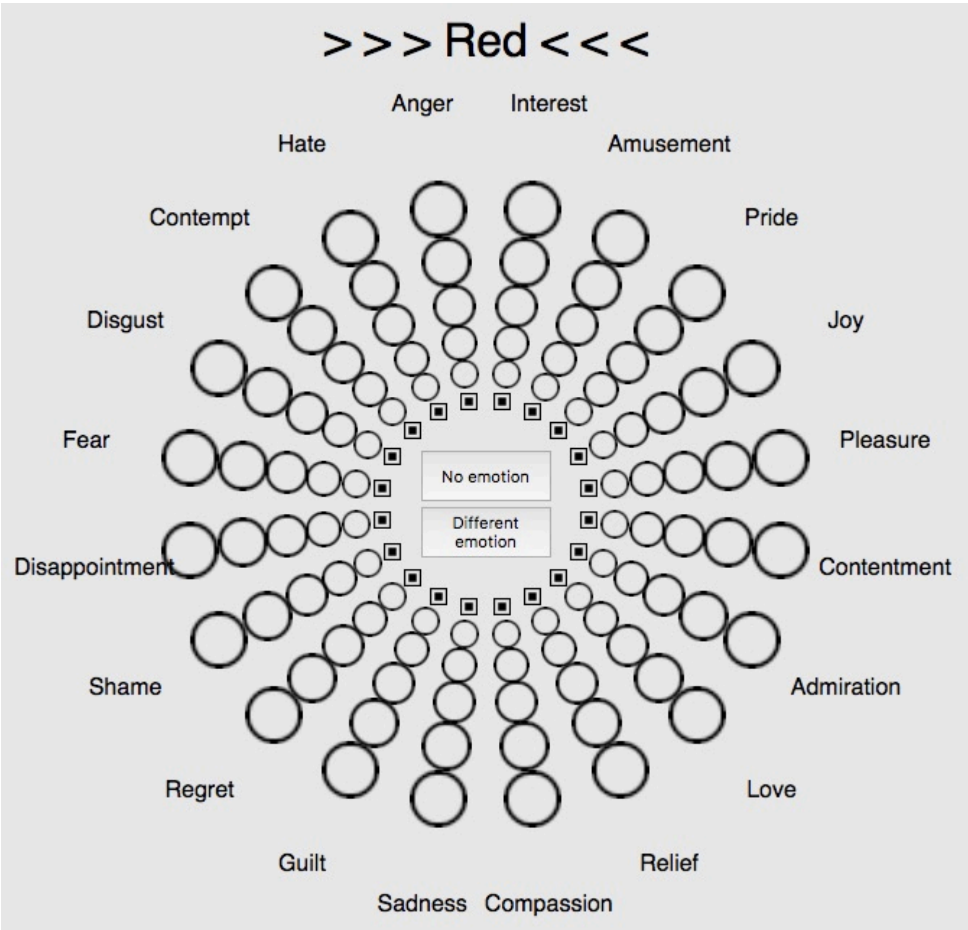

Figure 1.7. Geneva Emotion Wheel (GEW).

The GEW was used to assess the association of 20 emotion concepts with 12 colour terms. Participants selected the square to indicate no association between the given colour term and the given emotion, or selected one of the circles to indicate the intensity of the associated emotion. Intensity ranged from weak (smallest circle) to strong (largest circle). In addition, participants had a choice of *No emotion* or *Different emotion.* Table S4 provides the emotion terms we used in the languages reported in this study. Here, an example for colour term RED in English. See also (Scherer, 2005; Scherer et al., 2013).

The GEW is designed to assess the feeling component of emotional experiences elicited by particular events. It is based on the theoretical categorizations of emotions (Scherer, 2005) and validated through research (Scherer et al., 2013). GEW presents 20 specific emotions labelled with standard emotion labels coming from a natural language (see Figure 1.7). These emotion labels should be interpreted as labelling the entire emotion family (i.e., *rage*, *irritation*, and *frustration* all fall under the emotion family of *anger*). The emotions are arranged in a circular fashion along two emotion dimensions – valence and power. Emotions similar in valence and power are placed close to each other on the GEW (see Figure 1.8 for the representation of these emotions in a two-dimensional space). The dimension of power rather than arousal had been chosen because arousal has limited usefulness in differentiating between emotion families [10]. Nevertheless, it is possible to identify 10 positive, 10 negative, 10 high power, 10 lower power, 10 arousing and 10 calming emotions on the GEW. In Chapter 3, I explain in detail how I arrived at the precise categorisation of the GEW emotions on these three affective dimensions. For completeness, Table 1.1 already presents the categorisation of the GEW emotions on valence, arousal, and power dimensions here.

Furthermore, the GEW allows a systematic assessment of the intensity of emotions. To this end, a square and five circles of increasing size, mapped from the hub to the rim of the wheel, signify five degrees of intensities of these emotions. The GEW went through several stages of development. We are using its most recent version – version 3.

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[10] While emotions from different emotion families (e.g., *joy* and *regret*) differ on all three affective dimensions, emotions within the same emotion family usually have similar ratings on valence and power. Therefore, it is relatively easy to compare emotions from different emotion families on valence and power dimensions. In contrast, members of the same emotion family often have different arousal ratings. For instance, *irritation* is less arousing then *rage* while they both belong to the *anger* family. This makes comparison between emotion families complicated.

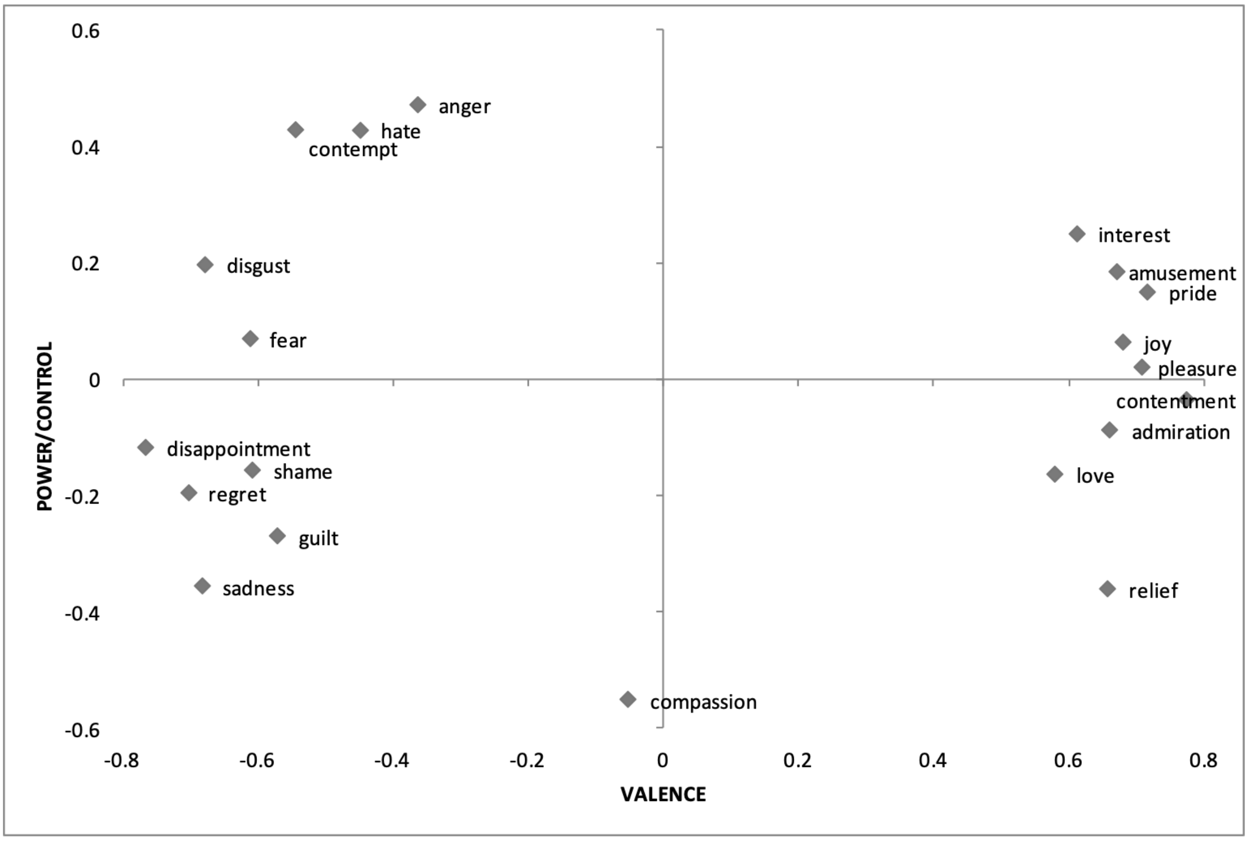

Figure 1.8. Empirical representation of the 20 GEW emotions in a two-dimensional space of Valence x Power in 10 countries.

Figure taken from (Scherer et al., 2013). This figure is similar to Figure 1.6A but represents all the GEW emotions, with ratings compiled across 10 countries and not only in the Swiss French speakers.

Table 1.1. Valence, Arousal, and Power loadings of the 20 GEW emotions.

Emotion	Valence	Arousal	Power
Interest	Positive	Low	Strong
Amusement	Positive	High	Strong
Pride	Positive	Low	Strong
Joy	Positive	High	Strong
Pleasure	Positive	High	Strong
Contentment	Positive	Low	Weak
Admiration	Positive	High	Weak
Love	Positive	High	Weak
Relief	Positive	Low	Weak
Compassion	Positive	Low	Weak
Sadness	Negative	Low	Weak
Guilt	Negative	High	Weak
Regret	Negative	Low	Weak
Shame	Negative	High	Weak
Disappointment	Negative	Low	Weak
Fear	Negative	High	Strong
Disgust	Negative	Low	Strong
Contempt	Negative	Low	Strong
Hate	Negative	High	Strong
Anger	Negative	High	Strong

Note. We show their categorisation regarding on emotion dimensions of valence, arousal, and power (Fontaine, 2013; Scherer, 2005; Scherer et al., 2013; Soriano et al., 2013). This categorisation was used in the empirical Chapters 3 and 5.

1.3. Colour and Emotion

"*Colour not only pleases by its thousand delicate hues and harmonious gradations, but serves in nature. (…) Every passion and affection of the mind has its appropriate tint; and colouring, if properly adapted, lends its aid, with powerful effect, in the just discrimination and forcible expression of them; it heightens joy, warms love, inflames anger, deepens sadness, and adds coldness to the cheek of death itself."* – John Opie, Cornish historical and portrait painter, 1807, Lecture IV, p. 141.

Colours carry certain affective meaning to most people. Examples of how colour is related to affect are omnipresent in natural languages. We *feel blue, see red,* are *green with envy,* feel *yellow-bellied,* and try to avoid *black days. W*e look through *rose tinted glasses* and wave *white flags*. Affective connotations of colour are also expressed in behaviour and cultural traditions (Hutchings, 2004). In the Western world, brides wear white dresses on their wedding days and mourners wear black clothing on funerals. In China, brides wear red and mourners wear white. Affective connotations of colour also manifest in the symbolic meanings of colour, endorsed by many (see Evarts, 1919). These colour meanings are further reinforced by numerous popular psychology articles and books, widely circulating the published and the online literature (e.g., (Causse, 2014; Lewis, 2014; Maximus, 2019). Such written pieces endorse many popular colour beliefs, for instance, that colour preferences reveal one's personality (Lüscher, 1969; Scott-Kemmis, 2018c; What's Your Personality Color, 2018) or that colours of one's environment influence one's affective states (Archon, 2019; Scott-Kemmis, 2018a). Such popular claims presuppose that colour-affect relationships are somewhat universal and stable – that is, they function similarly in many places of the world, across different contexts and conditions.

Obviously, with our linguistic, cultural, and perceptual environments being rich in affective colour meanings, colour-emotion associations can also be detected in controlled laboratory settings. Numerous empirical studies have demonstrated that lay people easily associate colours with emotions, whether emotions are defined as affective dimensions or as specific entities (Table 1.2). Such links have interested researchers from diverse disciplines, including but not limited to psychology (e.g., Meier et al., 2004), vision science (e.g., Hurlbert & Ling, 2007), biology (e.g., John, 2019), computer science (e.g., S. Wang et al., 2008), linguistics (e.g., Steinvall, 2007a), anthropology (e.g., D'Andrade & Egan, 1974), history (e.g., Pastoureau &

Simonnet, 2014), art (e.g., Maré & Liebenberg-Barkhuizen, 2018), design (e.g., Da Pos & Green-Armytage, 2007), architecture (e.g., Manav, 2017), medicine (e.g., Evarts, 1919), and marketing (e.g., Madden et al., 2000).

The section below is structured in the following manner. First, I make a short note on methodological considerations when testing colour-affect relationships with colour terms and colour patches. Afterwards, I highlight some important and influential previous empirical studies on the links between 1) colour and affective dimensions, and 2) colour and specific emotions. Since the distinction between colour terms and colour patches is important for the empirical Chapters 3 and 5, I have grouped the previous studies in both sub-sections accordingly. A particular emphasis is made on cross-cultural studies to highlight relevant previous results for universality of colour-emotion associations.

1.3.1. Some Methodological Considerations

When testing colour-affect relationships, researchers can either present colour terms or colour patches. Among the 100 publications summarised in Table 1.2, 21 publications tested colour terms, 72 publications tested colour patches (perceptual colours) in various forms, 4 publications tested both colour terms and colour patches, including two reported in this thesis, and 3 publications failed to report the method.

If colour terms are tested, the choice of colour terms is relatively straightforward. Researchers either present all or a subset of the basic colour terms, targeting the principal conceptual colour categories (e.g., Adams & Osgood, 1973; Sandford, 2014). Some researchers choose to augment the basic colour categories to also include non-basic colour terms (e.g., Goodhew & Kidd, 2017; Steinvall, 2007a). Whether non-basic terms are included or not, the researchers have only a vague idea about the perceptual colours these terms relate to. They can assume that participants imagine focal colours but they can never be sure. When working with terms, one must limit the analyses to mainly hue while ignoring the other two colour dimensions – saturation and lightness. Some exceptional cases exist when one can contrast responses to *white*, *grey*, and *black* to assess the influence of the lightness parameter or contrast responses to *brown* and *orange*, or to *pink* and *red*, to assess the influence of chroma as well as lightness parameters. Yet, overall, works with colour terms give information primarily on associations with hues.

If colour patches are tested, researchers have infinitely more options for stimuli. However, they must be aware of the inter-dependence of hue, saturation, and lightness. Using yellow and blue, I exemplify how colour parameters are inter-dependent. Imagine that you select the best example of yellow, which will most likely be both quite light and saturated. Now, try to select a blue that has both the same saturation and lightness as your yellow. When doing so, you will realise that you are unable to select such a blue, and would instead be limited to selecting a blue that is either darker but equally saturated as your yellow, or a blue that is equally light but less saturated than your yellow (Munsell, 1912). Hence, if you wanted to have a saturated blue and a saturated yellow of the same lightness, you would have to select a darker yellow to match the blue. This yellow, however, would be closer to brown than to ‘sunny’ prototypical yellows and likely would not have the same emotional connotations. That is, dark yellow is not associated with joy to the same extent as prototypical yellow or light yellow (Schloss et al., 2020). Researchers studying colour experiences can target psychological responses to ‘yellow’ and ‘blue’, but they have to also account for such inter-dependencies of colour parameters by relying on perceptually uniform models of human colour perception. Such inter-dependence complicates stimulus selection as well as a comparison of the results between different studies.

Table 1.2. The list of 100 empirical publications investigating colour-affect relationships, ordered chronologically from the oldest to the most recent publications.

Only studies/experiments testing healthy adult populations have been included. Apart from one case (Sandford, 2014), several studies appearing in the same publication have been presented together. “NA” signals that information is not relevant to the study (e.g., the number of participants in corpus-based studies). A question mark (“?”) signals missing information from the publication. A country name followed by a question mark (e.g., “USA?”) signals uncertainty regarding the country from which the participants came from. Common abbreviations: pps – participants, *M* = mean, USA – United States of America, UK – United Kingdom, SAM – Self-assessment manikin (see (Bradley & Lang, 1994).

No	Authors	Age	Country	N	% males	Colour method	Colours	Emotion method	Emotions
1	(Major, 1895)	?	USA	3	33%	colour patches	137 colours as well as 12 different shades of grey	affective words	valence: pleasant vs. unpleasant
2	(Dorcus, 1926)	?	USA	871	51%	colour patches	12 colours, 6 hues	affective words	free associations
3	(Allen & Guilford, 1936)	?	USA	10	50%	colour patches	90 colours	affective words	affective value
4	(Wexner, 1954)	?	USA?	94	49%	colour patches	8 colours	affective words	29 emotion terms (mood tones), grouped in 11 groups
5	(Murray & Deabler, 1957)	?	USA	25	72%	colour patches	8 colours	affective words	29 emotion terms (mood tones),

									grouped in 11 groups
6	(Schaie, 1961a)	?	USA	44 (across two conditions)	57%	colour patches	10 colours	affective words	30 emotion terms (mood tones), grouped in 12 groups
7	(Schaie, 1961b)	?	USA	20	?	colour patches	10 colours	affective words	29 emotion terms (mood tones), grouped in 11 groups
8	(Wright & Rainwater, 1962)	range = 16-65	Germany	3660	26%	colour patches	50 colours	affective words	24 semantic differential scales of Osgood. Factor analyses grouped into 6 dimensions
9	(Adams & Osgood, 1973; Osgood, 1971)	?	23 countries: USA, France, Belgium, Netherlands, Germany, Sweden, Finland, Costa Rica, Mexico, Italy, Serbia/Croatia,	between 805 and 920 (35-40 pps from each country)	100%	colour terms	7 colours	affective words	semantic differential scales, loading on evaluation (valence), potency (dominance), and activity (arousal)

			Greece, Turkish, Lebanon, Iran, Afghanistan, India, Bangladesh, Thailand, China (Hong Kong and mainland), Japan						
10	(D'Andrade & Egan, 1974)	?	USA: English and Tzeltal speakers	52 (26 per country)	?	colour patches	157 colours, 5 and 13 hues	affective words	9 emotion terms
11	(Jacobs & Hustmyer Jr, 1974)	Median = 20, range = 17-27	USA	24	100%	colour patches	4 colours	physiological response	arousal
12	(A. Johnson et al., 1986)	diverse age	Machiguenga Indians in Peru	18	44%	colour patches	157 colours, 5 and 13 hues	affective words	9 emotion terms
13	(Valdez & Mehrabian, 1994)	?	USA	250	41%	colour patches	76 colours	affective words	semantic differential scales loading on pleasure (24 scales), arousal (8 scales), and

									dominance (15 scales)
14	(Terwogt & Hoeksma, 1995)	M = 30, range = 20-56	The Netherlands	24 (adults only)	50%	colour patches	6 colours	affective words	6 emotion terms
15	(Collier, 1996)	?	USA	47 (across two studies)	?	colour patches	8 colours	affective words	8 emotion terms (Study 1) and 16 terms (Study 2)
16	(Hemphill, 1996)	?	Australia	40	50%	colour patches	10 colours	affective words	valence: free responses grouped to positive, negative, neutral
17	(Hupka et al., 1997)	M(range) = 18-26	Germany, Mexico, Poland, USA, and Russia	661 (120-157 per country)	33%	colour terms	12 colours	affective words	4 emotion terms
18	(Ziems et al., 1998)	young adults	USA	36	22%	colour patches	4 colours	mood induction	happy or sad moods
19	(Madden et al., 2000)	?	Austria, Brazil, Canada, Colombia, China (Hong Kong, mainland, Taiwan), USA	253 (22-49 per country)	?	?	10 colours	affective words	20 semantic differential scales

20	(Kaya & Epps, 2004)	M = 21, range = 18-25	USA?	98	45%	colour patches	13 colours	affective words	valence: positive and negative
21	(Leichsenring, 2004)	Mean age between 27 and 44	Germany	30 (healthy pps only)	46%	colour patches	2 colours: red vs. non-red	affective words	free associations
22	(Meier et al., 2004)	?	USA	169 (across eight studies)	?	colour patches (font colour)	2 colours: black and white	affective words	valence: positive and negative words
23	(Ou et al., 2004)	?	England and China	31 (14-17 per country)	?	colour patches	20 colours	affective words	10 affective scales ("colour emotion")
24	(Xin et al., 2004a)	18-22	Hong Kong (China), Japan, China	210	?	colour patches	218 colours	affective words	12 affective word pairs
25	(Xin et al., 2004b)	18-22	Hong Kong (China), Japan, China	210	?	colour patches	218 colours	affective words	12 affective word pairs
26	(Gao & Xin, 2006)	M = 20	Hong Kong (China)	70	50%	colour patches	218 colours	affective words	12 affective word pairs
27	(Da Pos & Green-Armytage, 2007)	? Wide range	Australia	44 (37 completed both parts)	21%	colour patches	1950 colours?	facial expressions	6 basic emotions

28	(Gao et al., 2007)	range = 17-24	Japan, Thailand, Hong Kong, Taiwan, Italy, Sweden, Spain	440	50%	colour patches	214 colours	affective words	12 affective word pairs
29	(Manav, 2007)	M = 32, range = 18-65	Turkey	50	40%	colour patches	41 colours	affective words	30 affective words
30	(Meier et al., 2007)	M = 19.8	USA	185 (across four studies)	38% (across four studies)	colour patches	different shades of grey	affective words	valence: positive and negative words
31	(Steinvall, 2007a)	NA	NA	NA	NA	colour terms	50 colour terms	affective words	135 emotion terms. Later categorised into 6 categories
32	(Clarke & Costall, 2008)	range = 18-21	UK	16	38%	colour terms	11 colours	affective words	free associations
33	(Moller et al., 2009)	?	USA	72 (study 2 only)	36%	colour patches (font colour)	3 colours	affective words	8 positive and 8 negative words
34	(Soriano & Valenzuela, 2009)	M = 24.2, range = 20-46	Spain	115	?	colour terms	4 colour categories	affective words	42 affective words loading on valence, arousal, and power dimensions.
35	(Carruthers et al., 2010), Study	M = 38.5, range =	UK	204	31%	colour patches	38 colours	affective words	valence: positive and negative

	2	18-72							
36	(Suk & Irtel, 2010)	M = 24.2, range = 20-46	Germany	85 (across two studies)	24%	colour patches	36 colours	affective words	SAM scales of valence, arousal, and power
37	(Strapparava & Özbal, 2010)	NA	English	NA	NA	colour terms	5 colours: blue, red, green, orange, purple, yellow	affective words	anger, aversion/disgust, fear, happiness/joy, sadness
38	(D. R. Simmons, 2011)	range = 18-22	UK	116 (across four studies)	28%	colour patches	40 colours (10 different in each study)	affective words	valence and arousal: pleasantness, unpleasantness, activating, calming
39	(Fetterman et al., 2012)	?	USA	265 (across two studies)	53% (across two studies)	colour patches (font colour)	3 colours	affective words	3 emotions
40	(Joosten et al., 2012)	M = 21.5, range = 18-31	Netherlands	51	40%	colour patches (ambient light colour)	4 colours	affective state	SAM scales of valence, arousal, and power
41	(Lakens et al., 2012)	M = 21	Netherlands	320 (across 6 studies)	38%	colour patches	2 colours: black and	affective words	valence: positive and negative

							white		words
42	(Lechner et al., 2012)	?	12 countries: Brazil, Canada, China, France, Germany, India, Italy, Japan, South Korea, Spain, the UK, the USA	2021	?	?	27 colours	affective words	11 affective words
43	(S. Wang & Ding, 2012)	M = 24, range = 20-29	China	20	90%	colour patches	52 colours	affective words	valence: positive and negative; arousal: calming-exciting
44	(Lakens et al., 2013a)	M = 22	Netherlands	205 (across three studies)	60% (across two experiments)	colour terms and colour patches	different shades of grey	affective words	valence: positive and negative
45	(Palmer, Schloss, Xu, et al., 2013)	?	USA and Mexico	121 (49-72 per country)	?	colour patches	37 colours	affective words, affective music and facial expressions	8 emotional descriptors, loading on affective

									dimensions (study 1). 3 Emotive faces (study 2)
46	(Buechner et al., 2014)	M = 23.3	Germany	159	7%	colour patches	2 colours: red and blue	facial expressions of humans or drawn characters	2 emotions
47	(Sandford, 2014), Study 1	NA	NA	NA	NA	colour terms	11 basic colour terms	affective words	any emotion term
48	(Sandford, 2014), Study 2	M range = 22-53, range = 22-84	USA	106 (across three exp.)	29%	colour terms	11 basic colour terms	affective words	any emotion term (2.1. & 2.2.) and 14 emotion categories (2.3)
49	(T. Wang et al., 2014)	M = 21	China	58 (across two studies)	43%	colour terms and colour patches	2 colours: red and blue	affective words	valence: positive and negative words
50	(Lucyk, 2014)	M = 22.3, range = 18-64 y.	Canada	42	38%	colour terms	Unrestricted	affective words	11 emotion terms
51	(van Paasschen et al., 2014)	M = 23.5, range = 19-38	Italy	19	32%	colour patches (visual artworks)	Unrestricted (artists' choice)	affective words	valence and arousal

52	(X. Zhang et al., 2014)	M = 21.5, range = 18-25	China	48	15%	colour patches	2 colours: black and white	affective words	valence: pleased, happy, depressed, repressed
53	(Gil & Le Bigot, 2015)	M = 20	France	44	45%	colour patches (background colour)	3 colours: red, green, and grey	facial expressions	1 emotion: surprise
54	(Lindborg & Friberg, 2015)	Median = 30, range = 20-55	Singapore	22	59%	colour patches	unrestricted sample of colours	affective film music	5 emotions
55	(Meier et al., 2015)	M = 35.0	USA	980	50%	colour patches (font colour)	2 colours: black and white	affective words	valence: positive and negative words
56	(AL-Ayash et al., 2016)	range = 20-38	Australia	24	46%	colour patches (walls)	7 colours	affective words	9 affective dimensions
57	(Bhattacharya & Lindsen, 2016)	M(range) = 21-27	UK	60 (across three studies)	33%	colour patches	varying shades of grey	affective music	56 musical pieces, 4 emotions
58	(Dael et al., 2016)	M = 22.4, range = 18-24	Switzerland	28	54%	colour patches	unrestricted sample of colours	bodily expressions	2 emotions: joy and fear
59	(Gil et al., 2016)	M = 19	France?	76 (across two studies)	0%	colour patches (background colour)	4 colours: green, pink, white, grey	facial expressions	2 emotions: happy and sad
60	(Gilbert et al., 2016)	young and	USA	110 (excluding	50%	colour patches	unrestricted sample of	affective words	20 emotion terms

		older adults		teenagers)			colours		
61	(Hanafy & Sanad, 2016)	range = 20-23	Oman	80	0%	?	9 colours	affective words	9 affective dimensions
62	(Sutton & Altarriba, 2016b)	?	USA	105	29%	colour terms	unrestricted sample of colours	affective words	valence: positive and negative words
63	(Sutton & Altarriba, 2016a)	M = 18.5, range = 18-23	USA	118 (across two studies)	44%	colour terms	4 colours	affective words	8 emotion terms
64	(Barchard et al., 2017)	M = 32, range = 18-64	USA and India	366 (161-205 per country)	55%	colour terms	7 colours	affective words	4 emotion terms
65	(Goodhew & Kidd, 2017)	M = 21.4	Australia?	25 (study 2)	28%	colour terms	unrestricted sample of colours	affective words	24 affective words
66	(Mentzel et al., 2017)	M = 23.1	Germany	29	52%	colour patches (font colour)	3 colours	affective words	dominance or rest-related words
67	(Hanada, 2018)	19-23	Japan	47	83%	colour patches	40 colours	affective words	27 emotion words

68	(Ou et al., 2018)	?	Argentina, China, France, Germany, Hungary, Iran, Japan, Spain, Sweden, Taiwan, Thailand, and the UK	658 (across all countries)	?	colour patches	A varying number of colours	affective words	4-20 affective scales ("colour emotion"), depending on the sample
69	(Specker et al., 2018)	M = 22 (across three studies)	Austria and Japan	122 (across three studies, 15-107 per country)	29%	colour patches	varying shades of blue or grey	affective words	valence: positive and negative words
70	(Specker & Leder, 2018)	M = 21 (across two studies)	Austria	30 (across two studies)	37%	colour patches	varying shades of grey	affective words	valence: positive and negative words
71	(Takahashi & Kawabata, 2018)	M = 25, range = 21-36	Japan	40	50%	colour patches	130 colours, 6 hues	affective words and schematic facial expressions	6 emotions
72	(Thorstenson et al., 2018)	M = 20	USA	330 (across four experiments	35%	colour patches (facial colour)	unrestricted sample of colours	affective words	6 emotion terms

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73	(Wilms & Oberfeld, 2018)	M = 23.4, range = 19-54	Germany	62	21%	colour patches	30 colours, 3 hues	affective schematic images (SAM) and physiological response	SAM scales of valence (pleasant-unpleasant) and arousal (calm-aroused); physiological recordings of electrodermal and cardiovascular activity
74	(Minami et al., 2018)	M = 23.3	Japan	20	70%	colour patches (facial colour)	3 colours: blue, red, grey	emotional faces	morphed faces from fear to anger
75	(Fugate & Franco, 2019)	? (29% between 25 and 34)	USA, Canada and India	150 (across both studies)	44% (study 2)	colour patches	23 colours (study 1) and 28 colours (study 2)	affective words	10 affective words (Study 1) and 20 affective words (Study 2).
76	(Griber et al., 2019)	M = 36.5, range = 19-78	Russia	103	39%	colour terms	12 colours	affective words	20 emotion terms, GEW

77	(Jonauskaite, Althaus, et al., 2019)	M = 20.3, range = 18-29	Switzerland	96	18%	colour patches	unrestricted sample of colours	induced mood	4 emotions
78	(Jonauskaite, Wicker, et al., 2019)	M = 36, range = 15-79	China, Germany, Greece, UK	711 (126-252 per country)	18%	colour terms	12 colours	affective words	20 emotion terms, GEW
79	(Jonauskaite, Dael, et al., 2019), Study 3	M = 32.7, range = 18-88	Switzerland	183	26%	colour terms	3 colours	affective words	valence, emotions categorised into positive and negative
80	(Peromaa & Olkkonen, 2019)	Median = 22, range = 18-50	Finland?	40 (across three studies)	18%	colour patches (facial colour)	facial colour changed to make it redder, yellower, bluer, or greener	facial expressions	1 emotion: anger
81	(Tham et al., 2019)	M = 21, range = 18-25	UK , Chinese in UK and Chinese in China	256 (74-108 per country; across three studies)	22%	colour patches	11 basic colour categories (study 1) and 320 colours (study 2)	affective words	free associations

82	(Kramer & Prior, 2019)	M = 19.9	UK	100 (adults only)	33%	colour patches (clothing colours)	6 colours	affective words	affective traits
83	(Jonauskaite, Abdel-Khalek, et al., 2019)	M = 33.9, range = 16-87	55 countries	6625	25%	colour terms	12 colours	affective words	20 emotions terms, GEW
84	(Y. Chen et al., 2020)	over 18	UK and China	30 (15 per country)	53%	colour patches	unrestricted sample of colours	affective words	30 words, some affective
85	(Goodhew & Kidd, 2020)	18-40	Australia?	34 (study 1)	24%	colour patches (font colour)	7 colours	affective words	valence: positive and negative words
86	(Güneş & Olguntürk, 2020)	M = 21.1, range = 17-26	Turkey	180	50%	colour patches (wall colours displayed in VR)	4 colours	facial expressions	6 basic emotions
87	(Schloss et al., 2020)	M = 23.8	USA	68 (across two studies)	30%	colour patches	32 colours	affective words	3 emotions
88	(Jonauskaite, Parraga, et al., 2020)	M = 20.52, range = 18-26	Switzerland	132	17%	colour terms and colour patches	12 colours	affective words	20 emotion terms, GEW
89	(Jonauskaite, Abu-Akel, et al.,	M = 35.4, range =	30 countries	4598	24%	colour terms	12 colours	affective words	20 emotion terms, GEW

	2020)	15-87							
90	(Demir, 2020)	M = 20.4, range = 18-25	Turkey	929	52	colour patches	9 colours	affective words	14 positive and 14 negative emotion words (some from GEW) + free choice
91	(Lipson-Smith et al., 2020)	range = 13-61	Australia	745	46%	colour patches (wall colours in VR)	40 colours	affective words	8 adjectives.
92	(Cha et al., 2020)	M = 21.3, range = 20-28 y.	Hong Kong (China)	55	87%	colour patches (wall colours in VR)	4 colours: red, green, blue, white	affective words	affective scales and physiological measurements (heart rate)
93	(Gupta & Gupta, 2020)	?	India	56	?	colour patches	5 colours	emotional pictures	emotional pictures
94	(Kawai et al., 2020)	M = 20.9	Austria	145	19%	colour patches (font colour)	2 colours: red and green	affective words	valence
95	(Ram et al., 2020)	?	Greece, Turkey, Cyprus	944	?	colour terms	12 colours	affective words	20 emotion terms, GEW
96	(Zaikauskaite et al., 2020)	range = 18-64	UK	605	50%	colour patches	Unrestricted	affective words	pride and guilt
97	(Saysani et al., 2021)	M = 29, range = 21-35	Australia	20 (sighted only)	50%	colour terms	9 colours	affective words	17 bipolar affective scales

98	(Jonauskaite et al., 2021)	M = 23	Switzerland	66 (non-colour-blind)	100%	colour terms and colour patches	12 colours	affective words	20 emotion terms, GEW
99	(Jonauskaite, Sutton, et al., 2021)	NA	NA	NA	NA	colour terms	11 colours	affective embeddings	valence: positive and negative
100	(Müller et al., in prep.)	M = 20.8, range = 18-29 (adults only)	Switzerland	41 (only adult participants)	49%	colour patches	11 colours	emotional faces	valence: positive and negative

1.3.2. *Colour and Affective Dimensions*

Colour Terms

Despite some early attempts (Allen & Guilford, 1936; Major, 1895), the groundwork to the modern understanding on the link between colour and affective dimensions was laid by Osgood and colleagues in 1950s. In their extensive research paradigm, Osgood and colleagues (Osgood et al., 1957) assessed the connotative meaning dimensions in languages, first in English and then in diverse other languages. In linguistics, researchers make a distinction between denotative and connotative meanings. While the denotative meaning refers to the idea that the word carries, its strict dictionary meaning, (e.g., toothbrush, beauty, money), the **connotative meaning** refers to the affective and imaginative associations of the word (e.g., good, bad, strong). The work of Osgood and colleagues revealed three affective connotative dimensions in languages – valence, power, and arousal.

The basic principle of their research paradigm comes from linguistics. The researchers identified a set of bipolar pairs of adjectives (i.e., **semantic differential scales**) used in the natural languages to describe various qualities of objects (e.g., *big-small, good-bad, fast-slow, hard-soft*, etc.). Then, they asked participants from 23 different cultures to rate a large number of words on these semantic differential scales. Often, the given words were rated in a metaphorical sense rather than the typical sense (e.g., evaluate *house* as *fast-slow*). Metaphorical sense did not pose much difficulty to the participants. Osgood and colleagues coined this set of 620 rated words the *Atlas of Affective Meanings.*

The *Atlas of Affective Meanings* also included some colour terms (results reported in Osgood, 1971, and Adams & Osgood, 1973). The included colour terms were *red, yellow, green, blue, black, white,* and *grey*, as well as the word *colour* itself. These words were rated on twelve semantic differential scales by samples of teenage males coming from 23 cultures and 20 countries, tested in their native languages. The chosen semantic differential scales were commonly used in all the studied languages and had the highest and purest factor loadings on valence, arousal, and power[11]. In regard to valence, their results revealed that the most positively evaluated word was *colour*, followed by *blue*, then *green* and *white*. The most negatively evaluated words were *black* and *grey*. *Red* and *yellow* appeared in the middle, suggesting that these terms were either neutral or ambivalent in terms of valence. In regard to power, their results revealed that *black* and *red* were evaluated as the most powerful, while all other colour terms were evaluated as relatively weak. This was particularly true for *yellow*, *white*, and *grey*. Finally, in regard to arousal, their results revealed that *red* was evaluated as the most arousing term, followed by the word *colour*. The least arousing terms were *black* and *grey*.

After comparing ratings of colour terms on the semantic differential scales in 23 cultural groups, Adams and Osgood (1973) concluded about a high degree of universality. In particular, the term *black* was rated the most consistently across the cultural groups, while the term *colour* was rated the least consistently. As possible sources of universality, they suggested **physiology of human vision**, **shared experiences as humans**, and **common cultural beliefs**, either stemming from ancient common origins or from more recent cultural influences.

Colour Patches

Two decades later, Valdez and Mehrabian (1994) opted to assess colour associations with affective dimensions in a controlled laboratory setting. They believed it was crucial to assess colour-affect associations with physical colours (i.e., colour patches) rather than with colour terms to understand the relationship between colour dimensions and affective dimensions. While a number of previous studies testing colour patches already existed (e.g., Dorcus, 1926; Major, 1895; Wexner, 1954), Valdez and Mehrabian (1994) pointed out some serious methodological drawbacks in these studies. In particular, many previous studies often did not

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[11] Adams and Osgood (1973) used terms *evaluation* to refer to valence, *potency* to refer to power, and *activity* to refer to arousal. I chose to continue using the labels *valence, power,* and *arousal* throughout the thesis to avoid unnecessary confusion.

select colour samples using a standardised system of colour notation (e.g., Munsell colour system or *CIE Lab*) and did not properly account for the inter-dependence between hue, saturation, and lightness. Thus, the results from previous studies are difficult to interpret, compare and generalise.

In their study, Valdez and Mehrabian (1994) presented 76 samples of 10 different hue families from the Munsell colour system to 250 participants. Each participant rated at least 7 colour samples and each colour sample was rated by approximately 25 participants. Such design allowed only for group-level comparisons. Participants were asked to focus on a single colour patch at a time and think "how this colour makes them feel". Then, participants rated each colour patch on the valence, arousal, and power scales, taken from an earlier related study (Mehrabian, 1978)[12]. The valence scale had 24 pairs of adjectives (e.g., *happy-cruel, affectionate-nasty*). These adjectives differed only in term of valence and had been previously rated almost equally in terms of arousal and power. The arousal scale had 8 pairs of adjectives (e.g., *troubled-dull, frustrated-sad*) and the power scale had 15 pairs of adjectives (e.g., *masterful-fascinated, violent-fearful*). In analogy with the valence scale, the arousal and power scales varied only on the dimension of interest while the end points of the scales had similar evaluations on the other two dimensions. Thus, the design of this study was comparable to the design of the study by Adams and Osgood (1973), with a crucial difference in colour presentation mode – patches rather than terms.

The results revealed that colour patches were systematically linked to affective dimensions. Brighter and more saturated colours were evaluated as more positive (pleasant) while darker and less saturated colours were evaluated as more arousing and more powerful. In terms of hue, shades of yellow were evaluated as least positive (pleasant), while shades of green-yellow were evaluated as most arousing and powerful. In comparison, shades of blue were evaluated

[12] Valdez and Mehrabian (1994) used terms *pleasantness* to refer to valence, *dominance* to refer to power, and *arousal* to refer to arousal. Like above, I chose to continue using the labels *valence, power,* and *arousal* throughout the thesis to avoid unnecessary confusion.

as most positive (pleasant), shades of purple-blue and yellow-red evaluated as least arousing, and shades of red-purple as least powerful. It is questionable what exactly the dimension of pleasantness assessed. Although it might be interpreted as assessing valence (i.e., positivity-negativity), it might have also assessed colour preferences (i.e., like-dislike). This could be the case when looking at the results, which highly resemble findings on colour preferences (e.g., Eysenck, 1941; Jonauskaite et al., 2016; Palmer & Schloss, 2010; A. E. Skelton & Franklin, 2019) and less so findings on valence of colours (see Table 1.3). Taken together, Valdez and Mehrabian (1994) demonstrated a systematic link between the dimensions of colour and the dimensions of affect.

Other Studies

Numerous other empirical studies used diverse methods to establish how colour terms or colour patches are associated with affective dimensions. Table 1.3 summarises findings from studies presented in Table 1.2 how the 12 colours (hues) are linked to valence, arousal, and power dimensions. In short, red is associated with positive as well as negative, active, and strong emotions. Orange is associated with positive and active emotions. Yellow is associated with mainly positive, active and weak emotions. Green and blue are associated with positive and calming emotions. Turquoise and pink are associated with positive emotions. Purple is associated with positive, calming, and weak emotions, although not in all studies. Brown is associated with negative and strong emotions. Grey is associated with negative, calming and weak emotions. White, or light colours, are associated with positive, calming and weak emotions. Finally, black, or dark colours, are associated with negative, arousing, and strong emotions. When it comes to saturation (or chroma), more saturated colours are associated with positive, arousing and strong emotions while less saturated (desaturated colours) are associated with negative but also strong emotions.

Apart from valence, arousal, and power, some researchers focused on other affective dimensions less closely related to the traditional understanding of emotion. These dimensions include warm-cool, active-passive, tense-relaxed, like-dislike, light-heavy, and so on (Ou et al., 2004, 2012, 2018; Sato & Inoue, 2016). In the original study by Ou and colleagues (Ou et al., 2004), three affective dimensions were particularly important for systematically distinguishing between colours – warm-cool, active-passive, and light-heavy. The authors reported that yellow, orange, and red colours, presented as patches, were more often rated as “warm” and “active” while blue, purple, and grey colours were more often rated as “cool” and “passive”. Light pastel colours of any hue were rated as “light” (in terms of weight) while dark or reddish colours were rated as “heavy”. Importantly, there was high agreement (72%-81%) on such ratings between British and Chinese participants (Ou et al., 2004) and well as between participants of 8 countries (Gao et al., 2007) and 12 countries (Ou et al., 2018). Hence, the authors concluded that colour associations with these affective dimensions are “culture-independent”.

Table 1.3. Colour (hue) associations with valence, arousal and power dimensions.

Each dimension is further separated to levels – positive vs. negative for valence, arousing/active vs. calming for arousal, and strong/dominant vs. weak for power. Publications that report associations between each colour (hue) and levels of emotion dimensions appear in the columns “reference(s)”. The counts of such publications per colour and level appear in the column “n”. More details on these publications are presented in Table 1.2.

	Valence				**Arousal**				**Power**			
	Positive		**Negative**		**Active/ Arousing**		**Calming**		**Strong/ Dominant**		**Weak**	
Colour	***n***	**Reference(s)**	***n***	**Reference(s)**	***n***	**Reference(s)**	***n***	**Reference(s)**	***n***	**Reference(s)**	***n***	**Reference(s)**
Red	9	(Demir, 2020; Hemphill, 1996; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Ram et al., 2020; Soriano & Valenzuela, 2009; T. Wang et al., 2014)	5	(Cha et al., 2020; D’Andrade & Egan, 1974; Gil & Le Bigot, 2015; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Joosten et al., 2012; Kawai et al., 2020; Moller et al., 2009; Müller et al., in prep.; Ram et al., 2020; Sutton & Altarriba, 2016b; T. Wang et al., 2014)	17	(Adams & Osgood, 1973; AL-Ayash et al., 2016; Cha et al., 2020; Y. Chen et al., 2020; Clarke & Costall, 2008; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Joosten et al., 2012; Madden et al., 2000; Saysani et al., 2021; Schaie, 1961a; D. R. Simmons, 2011; Suk	0	-	1	(Adams & Osgood, 1973; Jonauskaite et al., 2021; Mentzel et al., 2017; Murray & Deabler, 1957; Schaie, 1961b; Soriano & Valenzuela, 2009; Wexner, 1954)	0	-

						& Irtel, 2010; Wexner, 1954; Wilms & Oberfeld, 2018)						
Orange	8	(Carruthers et al., 2010; Demir, 2020; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Sutton, et al., 2021; Müller et al., in prep.; Ram et al., 2020)	0	-	5	(Y. Chen et al., 2020; Clarke & Costall, 2008; Saysani et al., 2021; Schaie, 1961a, 1961b)	1	(D. R. Simmons, 2011)	2	(Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020)	0	-
Yellow	4	(Carruthers et al., 2010; Demir, 2020; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Joosten et al., 2012; Kaya & Epps, 2004; Müller et al., in prep.; Ram et	3	(D'Andrade & Egan, 1974; Suk & Irtel, 2010; Valdez & Mehrabian, 1994)	10	(AL-Ayash et al., 2016; Clarke & Costall, 2008; Gilbert et al., 2016; Hanafy & Sanad, 2016; Jonauskaite, Parraga, et al., 2020; Murray & Deabler, 1957; Saysani et al., 2021;	1	(Soriano & Valenzuela, 2009)	2	(Jonauskaite, Parraga, et al., 2020; Valdez & Mehrabian, 1994)	3	(Adams & Osgood, 1973; Soriano & Valenzuela, 2009; Suk & Irtel, 2010)

		al., 2020; Soriano & Valenzuela, 2009; Suk & Irtel, 2010; Sutton & Altarriba, 2016b)				Schaie, 1961a, 1961b; D. R. Simmons, 2011)					
Green	16	(Adams & Osgood, 1973; D’Andrade & Egan, 1974; Demir, 2020; Gil & Le Bigot, 2014, 2015; Goodhew & Kidd, 2017; Hemphill, 1996; Jonauskaite, Sutton, et al., 2021; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Kaya & Epps, 2004; Moller et al., 2009; Ram et al., 2020; Soriano & Valenzuela, 2009; Valdez & Mehrabian,	0	-	0	-	5	(Cha et al., 2020; Clarke & Costall, 2008; Saysani et al., 2021; Soriano & Valenzuela, 2009; Suk & Irtel, 2010)	1	(Jonauskaite, Parraga, et al., 2020)	0	-

		1994)								
Turquoise	7	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Müller et al., in prep.; Ram et al., 2020; Valdez & Mehrabian, 1994)	0	-	0	-	0	-	0	-	0	-
Blue	18	(Adams & Osgood, 1973; AL-Ayash et al., 2016; D'Andrade & Egan, 1974; Demir, 2020; Hemphill, 1996; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Dael, et al., 2019; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Sutton, et al., 2021; Kaya & Epps, 2004; Lipson-Smith et al., 2020; Müller et al., in prep.;	1	(Soriano & Valenzuela, 2009)	0	-	9	(AL-Ayash et al., 2016; Cha et al., 2020; Clarke & Costall, 2008; Jacobs & Hustmyer Jr, 1974; Saysani et al., 2021; D. R. Simmons, 2011; Soriano & Valenzuela, 2009; Suk & Irtel, 2010; Wilms & Oberfeld, 2018)	1	(Suk & Irtel, 2010)	2	(Jonauskaite, Parraga, et al., 2020; Mentzel et al., 2017)

		Ram et al., 2020; Suk & Irtel, 2010; Valdez & Mehrabian, 1994; T. Wang et al., 2014; Wilms & Oberfeld, 2018)										
Purple	6	(Demir, 2020; Jonauskaite et al., 2021; Kaya & Epps, 2004; Müller et al., in prep.; D. R. Simmons, 2011; Valdez & Mehrabian, 1994)	2	(D'Andrade & Egan, 1974; Ram et al., 2020)	0	-	3	(Clarke & Costall, 2008; Hanafy & Sanad, 2016; D. R. Simmons, 2011)	2	(Murray & Deabler, 1957; Schaie, 1961a)	1	(Clarke & Costall, 2008)
Pink	10	(Carruthers et al., 2010; Gil & Le Bigot, 2014; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Dael, et al., 2019; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Sutton, et al., 2021; Müller et al., in prep.; Ram et al.	1	(Lipson-Smith et al., 2020)	2	(Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020)	0	-	0	-	0	-

		al., 2020; D. R. Simmons, 2011)										
Brown	1	(Jonauskaite, Sutton, et al., 2021)	6	(Carruthers et al., 2010; Y. Chen et al., 2020; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Müller et al., in prep.; D. R. Simmons, 2011)	0	-	2	(Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020)	1	(Murray & Deabler, 1957)	0	-
Grey	0	-	11	(Adams & Osgood, 1973; Carruthers et al., 2010; Demir, 2020; Gil & Le Bigot, 2014; Hemphill, 1996; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Kaya & Epps, 2004; Müller et al., in prep.; Ram et al., 2020)	0	-	3	(Adams & Osgood, 1973; Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020)	0	-	5	(Adams & Osgood, 1973; Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Mentzel et al., 2017)
White/ Light	34	(Adams & Osgood, 1973; Bhattacharya &	0	-	0	-	6	(Cha et al., 2020; Jonauskaite,	0	-	4	(Adams & Osgood, 1973;

Lindsen, 2016; Clarke & Costall, 2008; Dael et al., 2016; Demir, 2020; Gao et al., 2007; Gil & Le Bigot, 2014; Griber et al., 2019; Hemphill, 1996; Jonauskaite, Althaus, et al., 2019; Jonauskaite, Parraga, et al., 2020; Jonauskaite et al., 2021; Kaya & Epps, 2004; Lakens et al., 2012, 2013a; Lindborg & Friberg, 2015; Meier et al., 2004, 2007, 2015; Moller et al., 2009; Ou et al., 2018; Palmer, Schloss, Xu, et al., 2013; Ram et al., 2020; Schloss et al., 2020; Specker et	Parraga, et al., 2020; Lechner et al., 2012; Saysani et al., 2021; Schaie, 1961a; S. Wang & Ding, 2012)	D’Andrade & Egan, 1974; Gao & Xin, 2006; Jonauskaite, Parraga, et al., 2020)

		al., 2018; Specker & Leder, 2018; Sutton & Altarriba, 2016b; Takahashi & Kawabata, 2018; Valdez & Mehrabian, 1994; van Paasschen et al., 2014; S. Wang & Ding, 2012; Wilms & Oberfeld, 2018; Wright & Rainwater, 1962; X. Zhang et al., 2014)										
Black/ Dark	1	(Demir, 2020)	30	(Adams & Osgood, 1973; Bhattacharya & Lindsen, 2016; Y. Chen et al., 2020; Clarke & Costall, 2008; Dael et al., 2016; Gao et al., 2007; Goodhew & Kidd, 2017; Griber et al., 2019; Hemphill, 1996; Jonauskaite, Althaus, et al., 2019;	4	(Adams & Osgood, 1973; Valdez & Mehrabian, 1994; van Paasschen et al., 2014; S. Wang & Ding, 2012)	1	(Jonauskaite, Parraga, et al., 2020)	9	(Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao & Xin, 2006; Kaya & Epps, 2004; Lechner et al., 2012; Schaie, 1961a, 1961b; Valdez & Mehrabian, 1994; Wexner,	0	-

Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Kaya & Epps, 2004; Lakens et al., 2012, 2013a; Meier et al., 2004, 2007, 2015; Müller et al., in prep.; Ou et al., 2018; Palmer, Schloss, Xu, et al., 2013; Ram et al., 2020; Specker et al., 2018; Specker & Leder, 2018; Takahashi & Kawabata, 2018; van Paasschen et al., 2014; S. Wang & Ding, 2012; X. Zhang et al., 2014)	1954)

Saturated	10	(D'Andrade & Egan, 1974; Dael et al., 2016; Jonauskaite, Althaus, et al., 2019; Major, 1895; Palmer, Schloss, Xu, et al., 2013; Schloss et al., 2020; Suk & Irtel, 2010; van Paasschen et al., 2014; Wilms & Oberfeld, 2018; Wright & Rainwater, 1962)	0	-	4	(Gao & Xin, 2006; Suk & Irtel, 2010; Valdez & Mehrabian, 1994; Wilms & Oberfeld, 2018)	0	-	2	(Suk & Irtel, 2010; Valdez & Mehrabian, 1994)	0	-
Desaturated	0	-	7	(D'Andrade & Egan, 1974; Da Pos & Green-Armytage, 2007; Dael et al., 2016; Jonauskaite, Althaus, et al., 2019; Palmer, Schloss, Xu, et al., 2013; Suk & Irtel, 2010; van Paasschen et al., 2014)	0	-	1	(Gao & Xin, 2006)	1	(D'Andrade & Egan, 1974)	0	-

1.3.3. *Colour and Specific Emotions*

Studies reviewed so far treated emotions as points on the affective dimensions and were designed to assess the relationship between colour and these affective dimensions. While such an approach is useful to get the first glance into the meaning of colour, it might also lead to misunderstanding some colour-emotion relationships. A particular example is the affective meaning of red. The observation that red appears in the middle of the valence dimension might lead to conclusion that red is an emotionally neutral colour. However, instead of being neither positive nor negative, red seems to be associated with both positive and negative emotions, such as *love* and *anger* (Table 1.4). The ambivalent nature of red can only be captured with more precise emotions assessment methods – that is, by treating emotions as specific concepts and by allowing many-to-many associations. Only then, the entire richness of colour-emotion associations can be documented. In analogy to the above*,* studies below are separated by colour presentation mode – colour terms or colour patches. These studies assessed colour associations with specific emotions.

Colour Terms

In an influential study [13], Hupka and colleagues (Hupka et al., 1997) assessed associations between 12 colour terms and four emotions in five nations – the USA, Germany, Poland, Russia, and Mexico. They chose the 11 basic colour terms in English together with *violet* as colour stimuli and the terms *anger*, *envy*, *fear*, and *jealousy* as emotion stimuli. Participants were asked to indicate the extent to which each emotion term reminded them of each colour term. The authors reported both commonalities and differences between the five studied cultures. In terms of commonalities, they observed that *anger* and *fear* were both associated with *red* and

[13] The article has been cited 242 times by March 2021 (Google Scholar)

black in all nations with an exception of Mexico [14]. *Red* was also associated with *jealousy* in every nation and almost every nation associated *envy* and *jealousy* with *black* (with an exception of Germany and Poland). In terms of cross-cultural differences, most differences occurred for colour associations with the terms *envy* and *jealousy.* Various colour terms, in addition to *red*, were associated with these emotion terms: *jealousy* and *yellow* in Germany and Russia, *jealousy* and *purple* in Poland, *envy* and *green* in the USA, *envy* and *yellow* in Russia, etc.. Another difference occurred for *anger* in Poland, as Polish participants were the only ones to associate *anger* with *purple* in addition to *red* and *black.*

One can conclude there are many-to-many rather than one-to-one associations between colours and emotions. Some of these associations are common to all five studied nations while others vary between the nations. Associations vary more between nations when colours are linked to *envy* or *jealousy* and less when linked to *anger* or *fear*. The authors suggested that *envy* and *jealousy* had a higher degree of social construction than *anger* and *fear*. They called *anger* and *fear* "primary" emotions. As potential mechanisms, Hupka and colleagues suggested that universality in colour associations with *anger* and *fear* may originate in "**sensory experiences common to all human beings**" while colour associations with *envy* and *jealousy* may be "**product of the culture**" (Hupka et al., 1997, p. 166).

Colour Patches

Some years later, Kaya and Epps (2004) tested affective associations with colour patches. Their study was focused on hue and lightness, as they included three achromatic colours – white, grey, and black, – as well as 10 fully saturated chromatic hues from the Munsell Colour System – red, yellow-red, yellow, green-yellow, green, blue-green, blue, purple-blue, purple, and red-purple. Students from the USA had to respond what emotional response they associate with each colour and how each colour makes them feel in an open answer format. After grouping

[14] In Mexico, the *red-fear* association did not reach the threshold to be considered an important association.

emotions by valence, Kaya and Epps (2004) reported that 80% of responses to the chromatic hues were positive in contrast to only 30% of positive responses to the achromatic colours.

The most positive responses were given to green and yellow. Green was associated with *relaxation*, *calmness*, *happiness*, and *hope* while yellow was associated with *happiness*. Interestingly, an intermediate hue between the two (i.e., green-yellow) evoked negative associations of *disgust* due to reminiscence of *vomit* and *sickness*. Blue, red, purple, and white colours were ambivalent in terms of valence. On the one hand, these colours had positive connotations, such as blue was associated with *relaxation* and *calmness*, red with *love* and *romance*, purple with *relaxation*, *calmness*, *happiness*, and *excitement*, and white with *peace*, *hope*, and *innocence*. On the other hand, these colours had negative connotations, such as blue was associated with *sadness*, *depression*, and *loneliness*, red with *anger* and *blood*, purple with *sadness*, *tiredness*, and *boredom*, and white with *emptiness*, *loneliness*, and *boredom*. Finally, the achromatic colours – black and grey – were both associated with similar negative emotions but for different reasons. Black was associated with *sadness*, *depression*, *fear*, and *anger* due to reminiscence of *death*, *mourning*, *tragic events*, and *darkness*. Grey was associated with *sadness*, *depression*, *boredom*, and *confusion* due to reminiscence of *bad weather*. These results are similar to the results from the studies testing colour associations with emotion dimensions. Nonetheless, they also provide a more finely grained understanding of the emotional meaning of colours, especially when such meaning is ambivalent in terms of valence.

Other Studies

Many more associations between specific emotions and colours have been reported in previous studies (see Table 1.4). Some associations appeared in a single or a couple of publications, while other associations were reported in a larger number of publications. When looking at the most prevalent associations, mentioned in more than three studies, red was repeatedly associated with *anger* (and related emotions), *love*, *happiness*, *fear*, *enthusiasm*, *passion,* and *embarrassment* confirming its ambivalent nature. Orange was associated with *joy, amusement, excitement,* and *pleasure*. Yellow was associated with *joy*, *cheerfulness*, *excitement, amusement,* and *pleasure*. Green was associated with *calmness*, *joy*, *contentment*, feelings of *comfort* and of being *soothed*, as well as *envy* or *jealousy*. Turquoise was associated with *joy,* *pleasure,* and *relief,* while *blue* was associated with *sadness*, *calmness*, *relaxation*, feelings of *comfort* and of being *soothed*, as well as *joy*, and *contentment*. Purple was associated with diverse positive and negative emotions, including *pride*, *sadness*, and feelings of being *dignified*. Pink was associated with *love*, *joy,* and *pleasure*. Brown was associated with *disgust*. Grey was also associated with *sadness* (and related emotions), *fear, disappointment, boredom,* and *regret*. White was associated with *calmness* and *relief*. Finally, black was associated with *fear*, *sadness* (and related emotions), *anger*, *hate*, and feelings of being *powerful*.

Table 1.4. Colour (hue) associations with specific emotions.

Similar emotions were grouped together (e.g., calmness and peacefulness). Emotions are further separated into positive and negative for ease of comparison with Table 1.3. Publications that report associations between each colour (hue) and each specific emotion appear in the columns "reference(s)". The counts of such publications per colour appear in the column "n". More details on these publications are presented in Table 1.2.

	Positive			Negative		
Colour	***n***	**Emotion**	**Reference(s)**	***n***	**Emotion**	**Reference(s)**
Red	13	Love	(Clarke & Costall, 2008; Collier, 1996; Fugate & Franco, 2019; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Leichsenring, 2004; Lucyk, 2014; Ram et al., 2020; Sandford, 2014; Steinvall, 2007b)	25	Anger	(Barchard et al., 2017; Clarke & Costall, 2008; Fetterman et al., 2012; Fugate & Franco, 2019; Gilbert et al., 2016; Hupka et al., 1997; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Kramer & Prior, 2019; Leichsenring, 2004; Lindborg & Friberg, 2015; Minami et al., 2018; Peromaa & Olkkonen, 2019; Ram et al., 2020; Sandford, 2014; Saysani et al., 2021; Schloss et al., 2020; Steinvall, 2007b; Sutton & Altarriba, 2016b; Takahashi & Kawabata, 2018; Tham et al., 2019)
	9	Happiness/ Joy	(Dael et al., 2016; Güneş & Olguntürk, 2020; A. Johnson et al., 1986; Jonauskaite et al., 2021; Jonauskaite, Wicker, et al., 2019; Murray & Deabler, 1957; Steinvall, 2007b; Wexner, 1954)	5	Fear/ Anxiety/Panic	(Fugate & Franco, 2019; Hupka et al., 1997; Lucyk, 2014; Sandford, 2014; Sutton & Altarriba, 2016b)

	5	Enthusiasm/ Excitement	(Demir, 2020; Hanada, 2018; Murray & Deabler, 1957; Sandford, 2014; Saysani et al., 2021)	4	Anger family: Fury, Irritation, Rage, Tense, Anguish	(Gilbert et al., 2016; Hanada, 2018; Sandford, 2014; Sutton & Altarriba, 2016b)
	4	Passion	(Clarke & Costall, 2008; Hanada, 2018; Sandford, 2014; Tham et al., 2019)	4	Embarrassment	(Collier, 1996; Lucyk, 2014; Sandford, 2014; Sutton & Altarriba, 2016b)
	3	Pleasure	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019)	3	Hate	(Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019)
	1	Admiration	(Jonauskaite, Wicker, et al., 2019)	3	Hostility	(Schaie, 1961a; Sutton & Altarriba, 2016b; Wexner, 1954)
	1	Amusement	(Jonauskaite, Wicker, et al., 2019)	2	Guilt	(Sutton & Altarriba, 2016b; Zaikauskaite et al., 2020)
	1	Contentment	(Jonauskaite, Parraga, et al., 2020)	2	Shame	(Sandford, 2014; Sutton & Altarriba, 2016b)
	1	Pride	(Jonauskaite, Wicker, et al., 2019)	1	Contempt	(Sutton & Altarriba, 2016b)
	1	Surprise	(Takahashi & Kawabata, 2018)	1	Disgust	(Güneş & Olguntürk, 2020)
				1	Jealousy	(Hupka et al., 1997)
Orange	10	Happiness/ Joy	(Clarke & Costall, 2008; Hanada, 2018; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Sandford, 2014; Saysani et al., 2021; Schaie, 1961a; Steinvall, 2007b)	1	Anger	(Gilbert et al., 2016)
	6	Amusement/Fun	(Demir, 2020; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite,	1	Distress	(Wexner, 1954)

			Wicker, et al., 2019; Ram et al., 2020)			
	4	Energising/ Excitement/ Stimulating/Enthusiasm	(Sandford, 2014; Schaie, 1961a, 1961b) (Demir, 2020)	1	Hostility	(Wexner, 1954)
	4	Pleasure	(Hanada, 2018; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019)			
	2	Cheerful	(Collier, 1996; Schaie, 1961a)			
	2	Contentment	(Jonauskaite et al., 2021; Jonauskaite, Wicker, et al., 2019)			
	2	Surprise	(Hanada, 2018; Lucyk, 2014)			
	1	Admiration	(Jonauskaite, Wicker, et al., 2019)			
	1	Calmness	(D. R. Simmons, 2011)			
	1	Carefree	(Collier, 1996)			
	1	Interest	(Jonauskaite, Wicker, et al., 2019)			
Yellow	30	Happiness/Joy	(Barchard et al., 2017; Clarke & Costall, 2008; Da Pos & Green-Armytage, 2007; Dael et al., 2016; Demir, 2020; Fugate & Franco, 2019; Goodhew & Kidd, 2017; Hanada, 2018; A. Johnson et al., 1986; Jonauskaite, Abdel-Khalek, et al., 2019; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Althaus, et al., 2019; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Jonauskaite et al., 2021; Kaya & Epps, 2004; Lindborg & Friberg, 2015;	2	Jealousy/ Envy	(Hupka et al., 1997; Sandford, 2014)

		Lucyk, 2014; Murray & Deabler, 1957; Palmer, Schloss, Xu, et al., 2013; Ram et al., 2020; Sandford, 2014; Saysani et al., 2021; Schaie, 1961a, 1961b; Schloss et al., 2020; Steinvall, 2007b; Takahashi & Kawabata, 2018; Terwogt & Hoeksma, 1995; Wexner, 1954)			
8	Cheerful	(Clarke & Costall, 2008; Collier, 1996; Goodhew & Kidd, 2017; Manav, 2007; Murray & Deabler, 1957; Schaie, 1961a, 1961b; Wexner, 1954)	1	Anger	(Terwogt & Hoeksma, 1995)
5	Energetic/ Excitement/ Stimulating/Enthusiasm	(Demir, 2020; Kaya & Epps, 2004; Murray & Deabler, 1957; Schaie, 1961a, 1961b)	1	Cowardice	(Sandford, 2014)
5	Amusement/Fun	(Demir, 2020; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019)	1	Disgust	(Sandford, 2014)
4	Pleasure	(Hanada, 2018; Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019)	1	Fear	(Sandford, 2014)
3	Surprise	(Hanada, 2018; Lucyk, 2014; Takahashi & Kawabata, 2018)	1	Worry	(Sandford, 2014)
2	Admiration	(Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020)			
1	Carefree	(Collier, 1996)			
1	Contentment	(Jonauskaite, Wicker, et al., 2019)			

	1	Hope	(Demir, 2020)			
	1	Interest	(Jonauskaite, Wicker, et al., 2019)			
	1	Lively	(Kaya & Epps, 2004)			
	1	Peaceful	(Manav, 2007)			
	1	Pride	(Lucyk, 2014)			
Green	9	Calmness/ Peacefulness/ Serenity	(Clarke & Costall, 2008; Demir, 2020; Hanada, 2018; Kaya & Epps, 2004; Madden et al., 2000; Manav, 2007; Murray & Deabler, 1957; Saysani et al., 2021; Wexner, 1954)	4	Envy/ Jealousy	(Fugate & Franco, 2019; Sandford, 2014; Sutton & Altarriba, 2016b; Tham et al., 2019)
	6	Happiness/ Joy	(Gil et al., 2016; Güneş & Olguntürk, 2020; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Terwogt & Hoeksma, 1995)	3	Disgust	(Fugate & Franco, 2019; Lucyk, 2014; Sutton & Altarriba, 2016b)
	4	Comfortable	(Clarke & Costall, 2008; Kaya & Epps, 2004; Murray & Deabler, 1957; Wexner, 1954)	2	Guilt	(Lucyk, 2014; Zaikauskaite et al., 2020)
	4	Contentment	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)	2	Sadness family: Depression, Gloom	(Manav, 2007; Sandford, 2014)
	4	Soothing	(Clarke & Costall, 2008; Collier, 1996; Hanada, 2018; Murray & Deabler, 1957)	1	Anger	(Steinvall, 2007b)
	3	Relaxation	(Kaya & Epps, 2004; Manav, 2007)	1	Embarrassment	(Collier, 1996)
	3	Energising/ Excitement	(Gilbert et al., 2016; Kaya & Epps, 2004; Manav, 2007)	1	Fear/ Anxiety	(Manav, 2007)
	2	Hope	(Kaya & Epps, 2004; Sandford, 2014)			

	3	Relaxation	(Kaya & Epps, 2004; Manav, 2007; Ram et al., 2020)		
	3	Pleasure	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019)		
	3	Relief	(Hanada, 2018; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019)		
	2	Amusement	(Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019)		
	2	Hope	(Kaya & Epps, 2004; Sandford, 2014)		
	2	Interest	(Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019)		
	1	Admiration	(Jonauskaite, Wicker, et al., 2019)		
	1	Carefree	(Collier, 1996)		
	1	Compassion	(Jonauskaite, Wicker, et al., 2019)		
	1	Gentle	(Madden et al., 2000)		
	1	Pride	(Zaikauskaite et al., 2020)		
Turquoise	5	Happiness/ Joy	(Fugate & Franco, 2019; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019)	0	-
	5	Pleasure	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)		

	4	Relief	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)			
	3	Contentment	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019)			
	1	Admiration	(Jonauskaite et al., 2021)			
	1	Amusement	(Jonauskaite, Wicker, et al., 2019)			
	1	Calmness	(Fugate & Franco, 2019)			
	1	Interest	(Jonauskaite, Wicker, et al., 2019)			
Blue	12	Calmness/ Peacefulness/ Serenity	(Collier, 1996; Demir, 2020; Fugate & Franco, 2019; Hanada, 2018; Kaya & Epps, 2004; Madden et al., 2000; Manav, 2007; Murray & Deabler, 1957; Sandford, 2014; Saysani et al., 2021; Schaie, 1961a; Wexner, 1954)	17	Sadness	(Barchard et al., 2017; Collier, 1996; Da Pos & Green-Armytage, 2007; Fugate & Franco, 2019; Gilbert et al., 2016; Hanada, 2018; Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Lindborg & Friberg, 2015; Lucyk, 2014; Palmer, Schloss, Xu, et al., 2013; Sandford, 2014; Saysani et al., 2021; Schloss et al., 2020; Steinvall, 2007b; Sutton & Altarriba, 2016b; Takahashi & Kawabata, 2018)
	6	Comfortable	(Clarke & Costall, 2008; Kaya & Epps, 2004; Murray & Deabler, 1957; Schaie, 1961a, 1961b; Wexner, 1954)	3	Sadness family: Depression, Sorrow, Unhappy	(Hanada, 2018; Kaya & Epps, 2004; Sutton & Altarriba, 2016b)
	5	Relaxation	(Hanafy & Sanad, 2016; Kaya & Epps, 2004; Manav, 2007; Saysani et al., 2021; Tham et al.,	2	Fear	(Dael et al., 2016; Sandford, 2014)

		2019)			
5	Relief	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)	1	Envy	(Sandford, 2014)
5	Soothing	(Clarke & Costall, 2008; Collier, 1996; Murray & Deabler, 1957; Schaie, 1961b; Wexner, 1954)	1	Guilt	(Lucyk, 2014)
4	Contentment	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004)	1	Regret	(Hanada, 2018)
4	Happiness/ Joy	(Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Sandford, 2014; Steinvall, 2007b)	1	Worry	(Hanada, 2018)
3	Admiration	(Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019)			
3	Pride	(Jonauskaite, Wicker, et al., 2019; Sandford, 2014; Zaikauskaite et al., 2020)			
3	Tenderness	(Murray & Deabler, 1957; Schaie, 1961b; Wexner, 1954)			
2	Compassion/Empathy	(Jonauskaite, Wicker, et al., 2019; Lucyk, 2014)			
2	Interest	(Jonauskaite et al., 2021; Jonauskaite, Wicker, et al., 2019)			
2	Pleasure	(Jonauskaite et al., 2021; Jonauskaite, Wicker, et al., 2019)			
1	Amusement	(Jonauskaite et al., 2021)			
1	Bliss	(Goodhew & Kidd, 2017)			

	1	Dignified	(Murray & Deabler, 1957)			
	1	Hope	(Demir, 2020)			
Purple	5	Pride	(Collier, 1996; Jonauskaite, Wicker, et al., 2019; Lucyk, 2014; Sandford, 2014; Zaikauskaite et al., 2020)	4	Sadness	(Hanada, 2018; Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Ram et al., 2020)
	4	Dignified	(Murray & Deabler, 1957; Schaie, 1961a, 1961b; Wexner, 1954)	2	Anger	(Sandford, 2014; Steinvall, 2007b)
	3	Masterful/ Powerful/ Strong	(Kaya & Epps, 2004; Murray & Deabler, 1957; Schaie, 1961a)	2	Fear	(Hanada, 2018; Kaya & Epps, 2004)
	2	Excitement/Enthusiasm	(Demir, 2020; Kaya & Epps, 2004)			
	2	Love	(Jonauskaite et al., 2021; Sandford, 2014)	2	Sadness family: Depression, Melancholy, Unhappy	(Hanada, 2018; Murray & Deabler, 1957)
	1	Admiration	(Jonauskaite, Wicker, et al., 2019)	1	Boredom	(Kaya & Epps, 2004)
	1	Amusement/Fun	(Demir, 2020)	1	Embarrassment	(Sandford, 2014)
	1	Calmness	(Kaya & Epps, 2004)			
	1	Cheerful	(Collier, 1996)	1	Guilt	(Zaikauskaite et al., 2020)
	1	Compassion	(Jonauskaite, Wicker, et al., 2019)	1	Jealousy	(Hanada, 2018)
	1	Contentment	(Jonauskaite, Wicker, et al., 2019)	1	Rage	(Sandford, 2014)
				1	Regret	(Hanada, 2018)
	1	Happiness	(Kaya & Epps, 2004)	1	Worry	(Hanada, 2018)
	1	Interest	(Jonauskaite, Wicker, et al., 2019)			
	1	Passion	(Sandford, 2014)			

	1	Pleasure	(Jonauskaite, Wicker, et al., 2019)			
	1	Regal	(Tham et al., 2019)			
	1	Relaxation	(Kaya & Epps, 2004)			
	1	Soothing	(Collier, 1996)			
Pink	9	Love	(Fugate & Franco, 2019; Hanada, 2018; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020; Sandford, 2014; Steinvall, 2007b)	1	Embarrassment	(Sandford, 2014)
	7	Happiness/ Joy	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020; Sandford, 2014; Steinvall, 2007b)			
	5	Pleasure	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Sandford, 2014)			
	3	Amusement	(Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)			
	1	Admiration	(Jonauskaite, Wicker, et al., 2019)			
	1	Bliss	(Goodhew & Kidd, 2017)			
	1	Cheerful	(Manav, 2007)			
	1	Compassion	(Jonauskaite et al., 2021)			
	1	Contentment	(Jonauskaite, Wicker, et al., 2019)			

	1	Enthusiasm/ Excitement	(Sandford, 2014)			
	1	Interest	(Jonauskaite, Wicker, et al., 2019)			
	1	Pride	(Zaikauskaite et al., 2020)			
Brown	1	Comfortable	(Wexner, 1954)	5	Disgust	(Fugate & Franco, 2019; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019)
				2	Boredom	(Collier, 1996; Sandford, 2014)
	1	Contentment	(Jonauskaite, Wicker, et al., 2019)	2	Sadness	(Madden et al., 2000; Schloss et al., 2020)
	1	Masterful/ Powerful/ Strong	(Murray & Deabler, 1957)	2	Sadness family: Depressed, Melancholy, Unhappy, Gloomy	(Collier, 1996; Wexner, 1954)
				1	Anger	(Jonauskaite, Wicker, et al., 2019)
				1	Contempt	(Jonauskaite, Wicker, et al., 2019)
				1	Disappointment	(Sandford, 2014)
Grey	0	-		12	Sadness	(Barchard et al., 2017; Da Pos & Green-Armytage, 2007; Fugate & Franco, 2019; Güneş & Olguntürk, 2020; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Ram et al., 2020; Sandford, 2014; Steinvall, 2007b)
				5	Fear/ Fright/ Terror/	(Demir, 2020; Jonauskaite et al., 2021;

					Anxiety	Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Sandford, 2014)
				5	Disappointment	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)
				4	Boredom	(Collier, 1996; Demir, 2020; Kaya & Epps, 2004; Sandford, 2014)
				4	Regret/ Remorse	(Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Sandford, 2014)
				4	Sadness family: Depression, Melancholy, Miserable, Unhappy	(Collier, 1996; Goodhew & Kidd, 2017; Kaya & Epps, 2004; Schaie, 1961b)
				2	Anger/ Fury	(Kaya & Epps, 2004; Sandford, 2014)
				2	Disgust	(Güneş & Olguntürk, 2020; Jonauskaite, Wicker, et al., 2019)
				2	Shame	(Fugate & Franco, 2019; Jonauskaite, Wicker, et al., 2019)
				1	Contempt	(Jonauskaite, Wicker, et al., 2019)
				1	Exhaustion	(Sandford, 2014)
				1	Guilt	(Jonauskaite, Wicker, et al., 2019)
White	5	Calmness/ Peacefulness/ Serenity	(Demir, 2020; Kaya & Epps, 2004; Sandford, 2014; Saysani et al., 2021; Schaie, 1961a)	2	Anger	(Sandford, 2014; Steinvall, 2007b)

	4	Relief	(Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)	2	Boredom	(Collier, 1996; Kaya & Epps, 2004)
	3	Happiness/ Joy	(Barchard et al., 2017; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)	2	Fear	(Sandford, 2014; Steinvall, 2007b)
	2	Admiration	(Jonauskaite et al., 2021; Jonauskaite, Wicker, et al., 2019)	1	Fury/ Rage	(Sandford, 2014)
	2	Hope	(Demir, 2020; Kaya & Epps, 2004)	1	Shock	(Sandford, 2014)
	1	Compassion	(Jonauskaite, Wicker, et al., 2019)			
	1	Contentment	(Jonauskaite, Wicker, et al., 2019)			
	1	Love	(Jonauskaite, Wicker, et al., 2019)			
	1	Pride	(Jonauskaite, Wicker, et al., 2019)			
	1	Relaxation	(Saysani et al., 2021)			
	1	Soothing	(Schaie, 1961b)			
	1	Tenderness	(Schaie, 1961b)			
Black	4	Masterful/ Powerful/ Strong	(Kaya & Epps, 2004; Schaie, 1961a, 1961b; Wexner, 1954)	14	Fear	(Barchard et al., 2017; Demir, 2020; Fugate & Franco, 2019; Hupka et al., 1997; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Lucyk, 2014; Ram et al., 2020; Sandford, 2014; Sutton & Altarriba, 2016b; Tham et al., 2019)
	3	Dignified	(Schaie, 1961a, 1961b; Wexner, 1954)	11	Sadness	(Barchard et al., 2017; Gilbert et al., 2016; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel,

					et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Kramer & Prior, 2019; Ram et al., 2020; Sandford, 2014; Saysani et al., 2021; Steinvall, 2007b)
1	Courage	(Demir, 2020)	9	Anger	(Collier, 1996; Hupka et al., 1997; Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019; Kaya & Epps, 2004; Kramer & Prior, 2019; Sandford, 2014; Saysani et al., 2021)
			8	Sadness family: Depression, Doom, Melancholy, Sorrow, Unhappy, Upset	(Goodhew & Kidd, 2017; Kaya & Epps, 2004; Murray & Deabler, 1957; Schaie, 1961a, 1961b; Sutton & Altarriba, 2016b; Tham et al., 2019; Wexner, 1954)
			6	Hate	(Jonauskaite et al., 2021; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020; Sandford, 2014)
			3	Distress	(Murray & Deabler, 1957; Schaie, 1961a, 1961b)
			3	Disappointment	(Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020)
			3	Guilt	(Jonauskaite et al., 2021; Jonauskaite, Wicker, et al., 2019; Zaikauskaite et al., 2020)
			3	Regret	(Jonauskaite et al., 2021; Jonauskaite, Parraga,

			et al., 2020; Jonauskaite, Wicker, et al., 2019)
	2	Hostility	(Murray & Deabler, 1957; Schaie, 1961b)
	2	Contempt	(Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019)
	2	Shame	(Fugate & Franco, 2019; Jonauskaite et al., 2021)
	1	Disgust	(Jonauskaite, Wicker, et al., 2019)
	1	Fury/ Rage	(Sandford, 2014)
	1	Jealousy	(Hupka et al., 1997)

1.3.4. Current State of Knowledge of Colour-Emotion Relationships

The studies presented above suggest there is a systematic link between colours and emotions. When studying specific emotions, it is apparent that colours and emotions are associated in many-to-many rather than one-to-one fashion and may have ambivalent associations. These studies further suggested that some colour-emotion links are rather universal, especially when colour associations with emotion dimensions are assessed or when emotions are “primary” (e.g., *fear* and *anger*). Other colour-emotion links seem to be more strongly shaped by one’s culture, in particular for “social” emotions (e.g., *envy* and *jealousy*).

The findings and conclusions of these studies invite to systematically test a larger range of emotions and a larger range of colours in a larger range of nations to identify which emotions exhibited more universal and which exhibited more culture-specific association patterns with colours. It is important to move beyond the well-studied nations, such as the USA (31 studies included participants from USA, see Table 1.2 for other countries), and also to incorporate a larger slice of society. In particular, the age of participants could be extended. Most previous studies assessed colour-emotion associations in school or university students (see Table 1.2), or exclusively focused on particular age groups such as children (e.g., Boyatzis & Varghese, 1994; Burkitt & Sheppard, 2014; Zentner, 2001) or elderly (e.g., Ou et al., 2012).

1.4. Psychological Universals

There are two statements about human beings that are true: that all human beings are alike, and that all are different. On those two facts all human wisdom is founded. – Mark Van Doren, American poet (1894–1972).

"**Human psychological universals are core mental attributes that are shared at some conceptual level by all or nearly all non-brain-damaged adult human beings across cultures**" (Norenzayan & Heine, 2005), p. 763). The entire field of psychology is built upon the assumption that human thoughts and behaviour are guided by psychological universals (for a review, see (Norenzayan & Heine, 2005). In other words, many psychologists work under the assumption that whatever they discover in a sample of one culture can be relatively easily generalised to apply to nearly all healthy humans on the planet. Not surprisingly then, most data in psychology comes from the **WEIRD** societies – **Western, Educated, Industrialised, Rich, and Democratic** (Henrich et al., 2010), may it be adults or their children. Instead of being a "gold standard", participants from such a population are often outliers in many psychological tasks including visual perception, fairness, cooperation, spatial reasoning, and categorisation. Few researchers in psychology consider ideas of **cultural relativism**, although more and more work is explicitly done in this domain (e.g., Boroditsky et al., 2011; Boroditsky & Gaby, 2010; Crivelli, Russell, et al., 2016; Davidoff et al., 1999; Majid et al., 2018).

Assumptions about universality can be traced to the origins of psychology as a field. The field of psychology has been profoundly influenced by biology in two aspects (Benjamin, 1988). Firstly, human observations are often contrasted with observations in other species (e.g., Crawford et al., 2012; Dunsmoor & Murphy, 2015; Harlow, 1958). The hope is that work on other species should reveal something about human functioning. This approach is especially viable in studies of mental diseases (e.g., Jankowsky et al., 2005; Jones et al., 2011; Yan et al., 2010). If other species are believed to share some mechanisms with humans, it goes without saying that humans from different cultures should also share the same mechanisms among each other. Secondly, psychology has inherited the theoretical foundations of the theory of evolution (Barkow et al., 1992; Pinker, 1997). The theory of evolution is based on the assumption of shared genomes across species. Again, if certain mechanisms are shared across species, they should be shared across all human cultures as well. In addition to the biological framework, since the cognitive revolution, the field of psychology has been heavily relying on the analogy between the human mind and a computer (Block, 1995). The human brain is seen as hardware and human mind as software. This analogy is based on the assumption of the universal building blocks of the human mind. The framework does acknowledge that culture may provide different inputs and thus human thoughts and behaviour (output) might also be different across cultures. Yet, such differences are considered to be minor and secondary (Norenzayan & Heine, 2005).

Assumptions in psychology about human universality contradict vast literature in anthropology documenting diversity of human cultures (e.g., Handwerker, 2002; Henrich & McElreath, 2003; Majumder, 1998; Scalco, 2019; Welsch et al., 1992). As humans are social beings with cognitive capacities allowing for massive cultural transmission among the in-group members, any behaviour must be in accordance with the members of one's social group. In other words, humans adapt extremely well to their environments, and so cultural diversity is expected in almost all aspects of human behaviour. That said, some anthropologists see the value in documenting universals in human nature (e.g., Hirschfeld & Gelman, 1994; Kluckhohn, 1953; Murdock, 1945; Paden, 2001; Wissler, 1923). The most extensive recent effort in anthropology was done by Brown (1991), who compiled a list of hundreds of characteristics that are human universals in his view. He included both category universals – marriage, rituals, language, etc., and content universals – fear of snakes, having colour terms for black and white, etc. Other anthropologists are less convinced that human psychological universals exist (e.g., Benedict, 1934; Geertz, 1973).

Overall, such discrepancies between the field of psychology and the field of anthropology make it both urgent and difficult to establish universal features of the human mind (Norenzayan & Heine, 2005). Urgent, because a large diversity of human cultures uncovered through anthropological research puts many assumptions in psychology, if not the entire field, into question. Difficult, because proper methodologies and theoretical foundations must be established before such questions can be properly addressed.

1.4.1. Testing For Psychological Universals

Establishing human psychological universals entails generalizability across diverse populations of humanity. A comparison across cultures can be seen as a particular case of generalizability (i.e., universality) across contexts and populations. In their review, Norenzayan and Heine (2005) proposed three cross-cultural strategies that could be used to study universality across cultures. The first and simplest strategy is to compare **two cultures** from different cultural contexts and look for convergent evidence on a psychological phenomenon of interest. For the strongest evidence of universality, one should choose two cultures that differ on as many theoretically relevant dimensions as possible such as social practices, cultural traditions, language, geography, literacy, education, and socioeconomic status. If the phenomenon of interest emerges in both cultures despite divergent contexts, this can be taken as evidence for universality (e.g., see Rosch Heider & Olivier, 1972) testing colour perception in groups with different number of basic colour terms – Americans and Papua New Guinea Dani). Similarly, **three cultures** could be compared (i.e., triangulation strategy) by first comparing two cultures which differ on a theoretically relevant dimension "A" and then comparing the third culture which differs from one but not the other of the previously studied cultures on another theoretically relevant dimension "B". This approach provides stronger evidence for universality if the same psychological phenomenon is observed in all three cultures. If the same phenomenon is not observed in all three cultures, the approach facilitates interpretations of cultural differences by shedding light on which psychological dimension could be important in explaining cultural differences.

Finally, the most powerful approach for establishing universality is **cross-cultural** surveys**,** especially when they include countries from different parts of the world and participants other than Western undergraduate students. In cross-cultural surveys, the same psychological phenomenon is assessed using the same measures in multiple cultures. The main strength of cross-cultural survey is their coverage of the world cultures. When a phenomenon of interest is clearly observable in a large and diverse array of cultures, one can make a compelling case for universality. This strategy has been employed in a number of high impact studies (Buss, 1989; Cordaro et al., 2018; Hofstede, 1980; Mehr et al., 2018; Schwartz, 1992) and also in this thesis.

1.5. Current Studies

The current studies are integrated into the frameworks of colour studies (see *What is colour?*) and emotion studies (see *What is emotion?*). These two domains usually talk little with each other, unless the relationships between colours and emotions are assessed (see *Colour & Emotion*). The literature reviewed so far has indicated that colours can be reliably associated with affective dimensions and specific emotions. Most of the previous studies, however, relied on a limited number of colours and emotions, and usually assessed these associations in a single culture. Even when cross-cultural studies were performed, they only assessed a handful of countries (e.g., Hupka et al., 1997; Ou et al., 2004; Palmer, Schloss, Xu, et al., 2013; Specker et al., 2018; see Table 1.2). A notable exception is the study by Adams and Osgood (1973) who assessed colour associations with affective dimensions in 23 countries. However, the latter study included only teenage males and assessed a subset of basic colour terms.

Large-scale modern cross-cultural studies are needed to establish the "topography" of colour-emotion associations outside the WEIRD societies (Henrich et al., 2010) and understand the extent to which such associations can constitute a human psychological universal. In particular, I question whether the patterns of colour-emotion associations are universal when specific emotions are considered and a large number of emotions are associated with a large number of colours. In addition to testing for universality in colour-emotion associations across cultures, I am also interested in understanding whether environmental factors, may they be climatological or perceptual, can further shape this potential human psychological universal. Higher degree of universality would indicate higher degree of information that can be shared non-verbally across cultures while influence of environmental factors would suggest sharing of information on a more local scale – within a culture and potentially with its neighbours.

From a more theoretical point of view, it is important to remark that the existing published literature does not differentiate between emotion associations with colours as term and as a patch (with an exception of T. Wang et al., 2014, see Table 1.2). Associations with colour terms would constitute more linguistic, or conceptual, associations, while associations with colour patches would constitute more perceptual associations. We have argued in the theoretical contribution (Mohr et al., 2018) that such a distinction is crucial to move the field forward. In particular, only knowing whether the same emotions or the same affective dimensions are associated with colour as a term and as a patch, can one start making predictions regarding the mechanisms at work for these associations. So far, researchers in linguistics, history, and other related fields mainly treat colour as a term while researchers in vision science and psychophysics mainly treat colour as a perceptual experience with little discussion between the two. We have highlighted these discrepancies in our recent theoretical account on this matter (Mohr & Jonauskaite, 2020), and our recent a commentary (Jonauskaite & Mohr, 2020). Such knowledge is crucial if one wishes to eventually transfer the findings to the applied domains.

With these concerns in mind, I structured the current thesis as follows. In Chapter 2, I tested for universality of the pattern of colour-emotion associations in 30 nations. In Chapter 3, assessed the similarity, and in a sense stability and universality, of colour-emotion associations across two colour assessment modes – as a term and as a patch. In Chapter 4, I tested whether the associations between *yellow* and *joy* varied as a function of physical environment – climatological differences. In Chapter 5, I tested whether colour-emotion associations were affected by colour-blindness – differences in perceptual environments within a single culture.

1.5.1. Common Methodology To All Studies

The four empirical chapters (Chapters 2-5) of the current thesis employ the same (or nearly the same) methodology to assess colour-emotion associations. The studies reported in these chapters are based on the International Colour-Emotion Association Survey, which was designed in 2013 and launched in 2015. The theoretical rationale for this survey was detailed in our previous publication (Mohr et al., 2018). The survey is still on-going and more participants from diverse countries are added every day. At specific time points, we have drawn the available data for analyses, many of which are reported in this thesis. We aim to include adult participants from different countries and of all ages to collect as representative colour-emotion associations as possible. So far, we have data from 81 countries with at least 5 participants (65 countries with at least 20 participants). The most recent counts of the participants of the International Colour-Emotion Association Survey are visible in Figure 1.9.

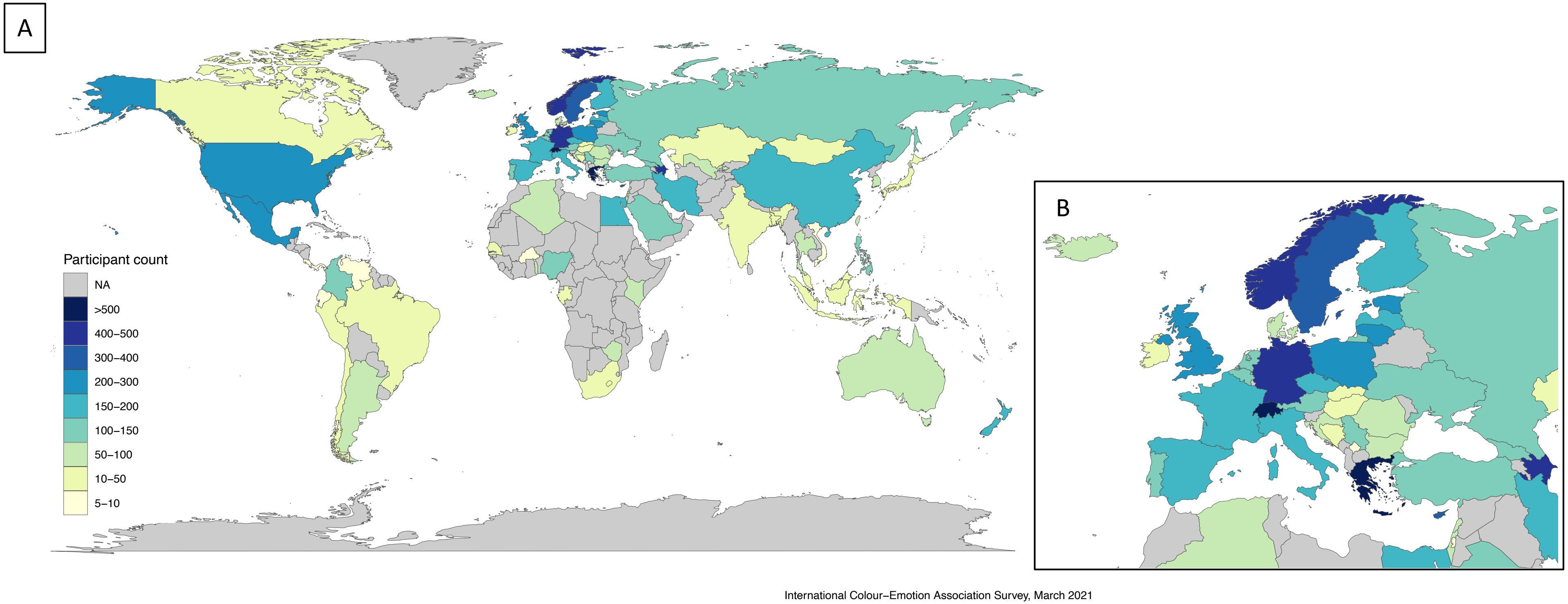

Figure 1.9. Counts of participants of the International Colour-Emotion Associations Survey.

(A) The map of the world. (B) The map of Europe (zoomed in). In both maps, bluer and darker colours indicate a greater number of participants, grey areas have no data (NA). Currently, we have collected data from 10,152 participants across 81 countries, as of 1st March 2021.

In all studies, participants are presented with 12 colours above the GEW. Participants are asked to choose as many or as few emotion concepts from the GEW that they believe are associated with the given colour. When choosing an emotion concept, participants also rate the intensity of that emotion concept from weak (1) to strong (5). Participants always complete the task in their native language. I have analysed both the presence of an associations (i.e., whether an emotion concept was chosen for each colour or not) and the intensity of the associated emotions. In Chapter 3 and 5, I additionally analysed colour-emotion associations as a function of affective dimensions of valence, arousal, and power. To this end, I grouped the specific GEW emotions according to their loadings on these dimensions (see Table 1.1).

In all four empirical chapters, I used colour terms as stimuli. In Chapters 3 and 5, I additionally used colour patches as stimuli. For colour terms, we chose to test the eleven basic colour terms (Berlin & Kay, 1969) – *red, orange, yellow, green, blue, purple, pink, brown, white, black,* and *grey* – as well as *turquoise*, since *turquoise* might be an emerging basic colour term in English as well as German (Mylonas & MacDonald, 2015; Witzel & Gegenfurtner, 2011; Zimmer, 1982; Zollinger, 1984) [15]. We also wanted to include this term because it covers a large perceptual area between green and blue (Mylonas & MacDonald, 2015). For colour patches, we chose to test 12 focal colours, matching the colour terms. Further details on the method and translations between languages can be found directly in the chapters.

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[15] A basic (or nearly basic) term describing a green-blue range of perceptual colours already exists in some other languages too such as Russian, Lithuanian, Italian, Spanish, and Greek (e.g., (Androulaki et al., 2006; Lillo et al., 2018; Paggetti et al., 2016; Paramei, 2005; Uusküla & Bimler, 2016a; Winawer et al., 2007).

1.5.2. Universal Patterns in Colour-Emotion Associations Are Further Shaped By Linguistic And Geographic Proximity

In Chapter 2, we tested the degree of cross-cultural universality of colour-emotion associations across 30 nations located on all continents but Antarctica (Jonauskaite, Abu-Akel, et al., 2020). We asked 4,598 participants (1,114 men) from 30 nations to associate 12 colour terms with 20 GEW emotion concepts in their native languages (22 languages in total) online. Participants had a wide age range (15-87 years old). With series of analyses, we assessed whether the pattern of colour-emotion associations was universal across all 30 nations by comparing the pattern of associations of each nation with a global pattern of associations (i.e., all nations barring the nation in question). Furthermore, we cross-culturally compared the average probability of associating any colour with any emotion and the pattern of associated emotion intensities. A machine learning algorithm was employed to assess if participants' nations could be predicted from their pattern of colour-emotion associations. Finally, a model was constructed to predict nation-to-nation similarity from the linguistic and geographic distances between the pairs of nations.

1.5.3. Similar Pattern of Emotion Associations With Colour Patches And Colour Terms

In Chapter 3, we assessed the degree of similarity in colour-emotion associations when colour was presented as a term and as a patch (Jonauskaite, Parraga, et al., 2020). In this between-subjects study, participants associated 20 GEW emotion concepts, loading on valence, arousal, and power dimensions, with 12 colours presented as patches (n = 54) or terms (n = 78). Using similar analyses to Chapter 2, we assessed the degree of similarity between the two colour presentation modes. Additionally, we compared associations with emotion dimensions, notably valence, arousal, and power, between the two colour presentation modes.

1.5.4. Physical Environments Affect How We Feel About Yellow Across 55 Countries.

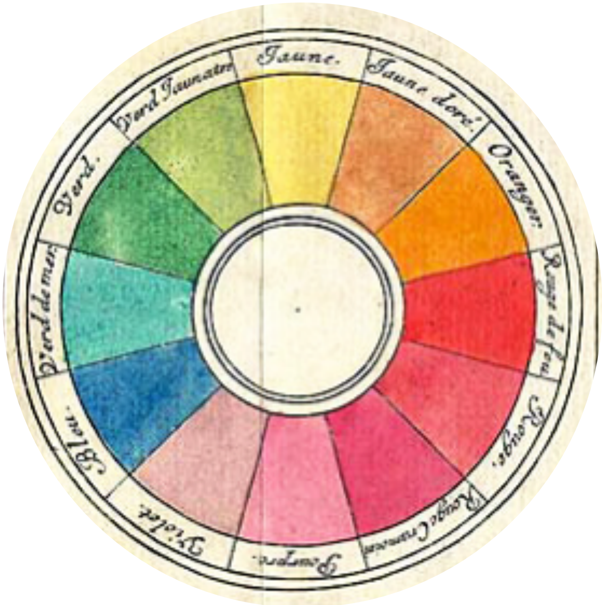
In Chapter 4, we assessed the importance of physical climatological environment for colour-emotion associations (Jonauskaite, Abdel-Khalek, et al., 2019). We focused on a prime example – the association between *yellow* and *joy*, – which conceivably arises because *yellow* is reminiscent of life-sustaining sunshine and pleasant weather. If so, this association should be especially strong in countries where sunny weather is a rare occurrence. We analysed the associations between yellow as a term and joy of 6,625 participants from 55 countries and 40 native languages. We investigated how *yellow-joy* associations varied geographically, climatologically, and seasonally by assessing the distance to the equator, sunshine, precipitation, and daytime hours as potential predictors of these associations.

1.5.5. Colour-Emotion Associations in Individuals With Red-Green Colour-Blindness

In Chapter 5, we assessed the importance of individual perceptual environment for colour-emotion associations (Jonauskaite et al., 2021). In particular, we contrasted colour-emotion associations between participants with and without red-green colour-blindness using identical methodology to Chapter 3. We compared colour associations with specific emotions as well as emotion dimensions between colour-blind (n = 64) and non-colour-blind (n = 66) participants. We also considered colour-blindness as a continuum, by assessing if the strength of colour blindness predicted the likelihood of colour-emotion associations.

Chapter 2.

Universal Patterns in Colour-Emotion Associations Are Further Shaped By Linguistic And Geographic Proximity [16]



[16] **Jonauskaite, D.,** Abu-Akel, A., Dael, N., Oberfeld, D., Abdel-Khalek, A. M., Al-Rasheed, A. S., Antonietti, J.-P., Bogushevskaya, V., Chamseddine, A., Chkonia, E., Corona, V., Fonseca-Pedrero, E., Griber, Y. A., Grimshaw, G., Hasan, A. A., Havelka, J., Hirnstein, M., Karlsson, B. S. A., Laurent, E., … Mohr, C. (2020). Universal Patterns in Color-Emotion Associations Are Further Shaped by Linguistic and Geographic Proximity. *Psychological Science*, *31*(10), 1245–1260. https://doi.org/10.1177/0956797620948810

2.1. Abstract

Many of us *see red*, *feel blue*, or *turn green* with envy. Are such colour-emotion associations fundamental to our shared cognitive architecture, or are they cultural creations learned through our languages and traditions? To answer these questions, we tested emotional associations of colours in 4598 participants from 30 nations, speaking 22 native languages. Participants associated 20 emotion concepts with 12 colour terms. Pattern similarity analyses revealed universal colour-emotion associations (average similarity coefficient $r = .88$). But, local differences were also apparent. A machine learning algorithm revealed that nation predicted colour-emotion associations above and beyond those observed universally. Similarity was greater when nations were linguistically or geographically close. This study highlights robust universal colour-emotion associations, further modulated by linguistic and geographic factors. These results pose further theoretical and empirical questions about the affective properties of colour, and may inform practice in applied domains like well-being and design.

2.2. Significance Statement

Why do we *see red*, *feel blue*, or *turn green* with envy? Are such associations between colour and emotion fundamental to our shared cognitive architecture? Or are they cultural creations learned through our languages and traditions? To answer these questions, we tested the emotional meaning of colours in 4598 participants from 30 nations, in 22 languages. Overall, participants associated similar emotion concepts with 12 colour terms. Moreover, similarity was higher between nations that share borders or languages. Colour-emotion associations have universal features, further shaped by a shared language and / or geography. These results pose further theoretical and empirical questions about the affective properties of colour, and may inform practice in applied domains such as well-being and design.

2.3. Introduction

Colour-emotion associations are ubiquitous (Adams & Osgood, 1973; Hupka et al., 1997; Madden et al., 2000; Major, 1895; Palmer, Schloss, Xu, et al., 2013; Valdez & Mehrabian, 1994; Wexner, 1954; Wilms & Oberfeld, 2018). Common wisdom would suggest that we *feel blue* when sad, *see red* when angry, and are *green with envy.* Yet, envy can be yellow or red if we come from Germany or Poland, respectively (see Hupka et al., 1997). And while westerners are likely to wear white to weddings and black to funerals, people from China prefer red for weddings and white for funerals. Wherever one comes from, such colour-emotion associations are intriguing because colours and emotions seem – at face value – to be fundamentally different "things". Colours are visual experiences driven by the wavelength of light. Emotions are subjective feelings, cognitions, and physiological responses that signal value. Are these cross-modal associations cultural creations, laid down in our languages and traditions? Or are they fundamental features of our cognitive architecture? Existing studies have identified both similarities (Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Ou et al., 2018) and differences (Hupka et al., 1997; Madden et al., 2000; Soriano & Valenzuela, 2009) across cultures. However, they have done so between only a small number of individual countries, making it nearly impossible to capture global patterns. In a series of analyses, we examined to what extent colour-emotion associations are universal, testing 4598 participants from 30 nations on 6 continents in 22 languages.

There are two theoretical explanations for colour-emotion associations, which make different predictions about the degree to which the emotional meanings of colour should be shared. According to the first view, colour-emotion associations arise through environmental experiences. That is, colours may become associated with emotions because they appear in particular emotional situations of evolutionary significance (e.g., *red* face in anger; Benitez-Quiroz, Srinivasan, & Martinez, 2018). If so, colour-emotion associations should be largely universal (in support, see Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Ou et al., 2018). According to the second theoretical explanation, colours and emotions may become arbitrarily associated in the language, history, religion, or folklore of one's culture. If so, colour-emotion associations should vary between cultures with different languages, symbolism, and traditions (Evarts, 1919; Soriano & Valenzuela, 2009). Such cross-cultural variations have also been reported (Hupka et al., 1997; Madden et al., 2000; Soriano & Valenzuela, 2009). While these views are often cast in opposition to each other, they are not mutually exclusive. According to the cross-modal correspondence framework (C. Spence, 2011), two unrelated entities (here, colours and emotions) can become cross-modally associated when they regularly appear together in one's perceptual *or* linguistic environment, whether on a global (shared by all) or local (shared by some) scale.

It is possible, therefore, that universal tendencies to associate certain colours with certain emotions are further modulated by cultural and individual factors. Consider red, an ambivalent colour that has been associated with both negative and positive emotions, depending on whether one comes from Western countries or China (Jonauskaite, Wicker, et al., 2019). The existence of both associations could be explained in evolutionary terms (e.g., red-blood pairings lead to associations with both danger and sexuality).In some countries like China, however, cultural beliefs that red is a symbol of good fortune might strengthen the link between red and positive emotions and weaken the link between red and negative emotions (see Wang, Shu, & Mo, 2014). In other countries, like the USA, the strong link between red and danger or failure could strengthen negative while weakening positive associations (Pravossoudovitch et al., 2014). Such additional variations might be maintained through language and geographic locations (see also Jackson et al., 2019; Jonauskaite, Abdel-Khalek, et al., 2019).

Existing studies provide examples of both similarities (Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Ou et al., 2018) and differences (Hupka et al., 1997; Madden et al., 2000; Soriano & Valenzuela, 2009) across countries. But these studies have focused on just a few countries, languages, or cultures, and so global patterns are still unknown. To test for the degree of universality, we performed a large-scale, cross-cultural survey on colour-emotion associations (for theoretical motivation, see Mohr, Jonauskaite, Dan-Glauser, Uusküla, & Dael, 2018). Participants completed the survey in their native language online. We exceeded previous investigations in terms of the number of tested nations, representativeness of participants, and the number of tested colours and emotions. We collected data from 4598 participants from 30 nations, located on all continents but Antarctica (Figure 2.1). Participants were aged between 15 and 87 years old and had normal colour vision. We used 12 colour terms representing the most common colour categories (Berlin & Kay, 1969; Mylonas & MacDonald,

2015) and an extensive list of 20 emotion concepts varying in valence and potency (Scherer, 2005). Participants chose as many emotion concepts as they thought associated with a given colour term and rated the intensity of the associated emotion from weak to strong.

In a series of analyses, we examined the degree of similarity across the 30 nations in *probabilities* of colour-emotion associations and *intensities* of associated emotions. We then applied a machine learning algorithm to quantify the degree of nation-specificity in colour-emotion associations. Finally, we assessed how colour-emotion associations varied as a function of linguistic and geographic distances.

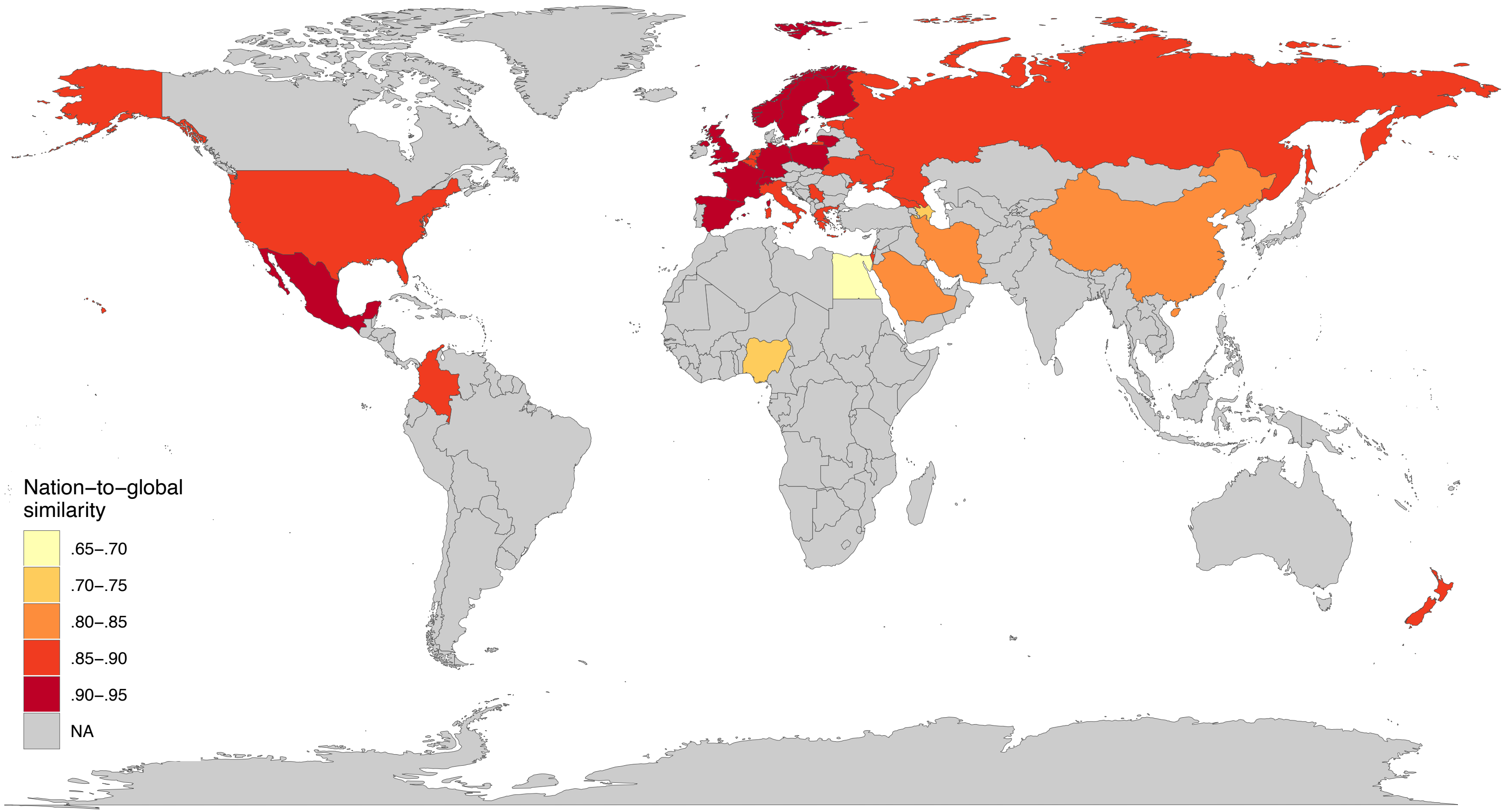


Figure 2.1. The world map of the 30 studied nations in Chapter 2.

The map is coloured by nation similarity with the global colour-emotion association pattern. Redder nations show colour-emotion association patterns more similar to the global mean (also see Figure 2.4 A).

2.4. Materials and Method

2.4.1. Participants

We extracted our data from the ongoing International Colour Emotion Association Survey (Mohr et al., 2018), performed online. This survey tests participants from a large age range using pre-defined age categories (15-29 years, 30-49 years, 50+ years). We started with the largest possible participant pool (*N* = 4883) consisting of data sets from countries for which we had at least 20 useable (e.g., without self-reported problems of colour vision) participants per age category (see also, Simmons, Nelson, & Simonsohn, 2011). We detail additional selection criteria under *Data preparation*. Our final sample (*n* = 4598, 1114 males) consisted of participants from 30 different nations (Figure 2.1) with a mean age of 35.4 (*SD* = 14.5). Counts per nation ranged from 69 to 490 participants. Table S 1 provides language information and Table S 2 provides demographic information of the participants of each nation. Participation was voluntary. The study was conducted in compliance with the ethical standards described in the Declaration of Helsinki. Parts of the data have been reported previously in relation to different research questions (Jonauskaite, Abdel-Khalek, et al., 2019; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019).

2.4.2. Material and Procedure

Emotion Assessment with The Geneva Emotion Wheel

The Geneva Emotion Wheel (GEW, version 3.0, Figure 2.2, Scherer, 2005; Scherer et al., 2013) is a self-report measure designed to assess the feeling component of emotional experiences elicited by particular events. It is based on theoretical categorizations of emotions and validated through research. The GEW represents 20 discreet emotions (e.g., *anger, fear, joy*) as spokes on a wheel. Emotion concepts that are similar in valence (*positive/negative*) and power (*high/low*) are placed close to each other. Each spoke of the wheel contains five circles that extend from a central square, representing increasing intensities of each emotion.

For each colour term, participants used a mouse click to indicate the associated emotions and their intensities (that is, they could indicate that a single colour term is associated with more than one emotion concept, see Figure 2.2). At the beginning of the trial, the central square was selected, indicating no emotion. Participants were also given the option to select "Different Emotion", which produced a pop-up window in which they could type the name of a different emotion. These responses were rare, and we did not analyse them.

Participants completed the GEW in their native language. The translation of the GEW was available for some languages on the Swiss Centre for Affective Sciences website. The remaining translations were created using the back-translation technique (see section *Translation of the GEW* in *Supplementary Material* for further details). See Table S 3 for emotion terms in each language.

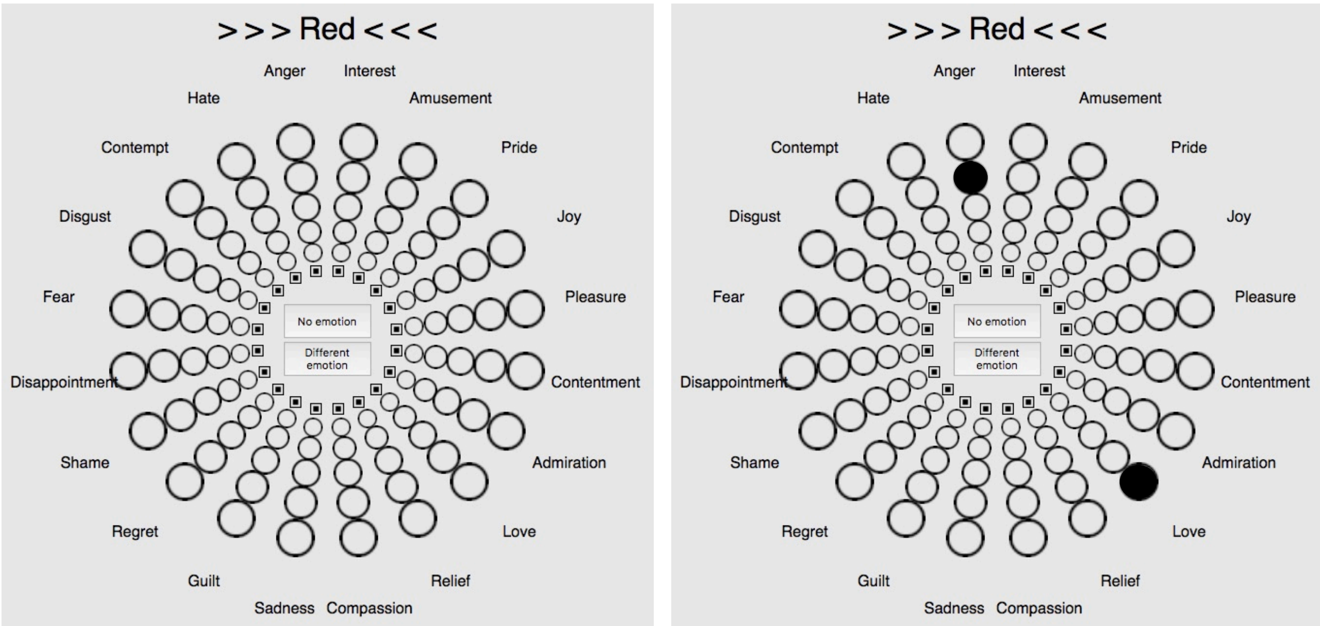


Figure 2.2. The GEW with the colour term red as an example.

The wheel was used to assess associations between 20 emotion concepts and 12 colour terms. Participants expressed emotion associations by selecting one of the five circles of each of the associated emotion. At the same time, they chose the intensity of the associated emotion, ranging from weak (smallest circle) to strong (largest circle). Participants could select as many or as few emotions as they thought appropriate. The right panel exemplifies a potential response from a participant for the colour term *red* associated with strong *love* and relative strong *anger*.

International Colour-Emotion Association Survey

We collected the current data online by sharing the survey link (http://www2.unil.ch/onlinepsylab/colour/main.php) with potential participants via university communications, e-mails, social media, and personal contact, mainly through our collaborators (co-authors) in each country. The survey was originally constructed in English and was translated (without back-translation) by co-authors and collaborators. We used links that automatically opened in the official language of the country to encourage participants to complete the survey in their native language. However, participants could switch to any other language provided. We only analysed data gathered from native speakers. Online data collection naturally resulted in literate participants with access to the Internet. Some elderly participants were helped with survey completion.

The first page described the aims of the study and ethical considerations; participants consented by clicking on the "Let's go" button. The following two instruction pages explained the task and the use of the GEW. We then used a manipulation check to verify that participants understood the task. Participants were presented with a situation and had to identify the correct responses. The situation read: "*Peter thinks that beige strongly represents intense compassion, and believes that beige is also associated with mild relief. Accidentally, he has selected sadness and wants to correct his choice. Look at his response in the emotion wheel below and try to correct it*". Participants saw the largest circle for *sadness* marked (emotion intensity 5). They could only move to the next page and start the survey if they successfully corrected Peter's responses. They had to click on the square for *sadness* (no association, rating 0), the largest circle for *compassion* (emotion intensity 5), and the middle circle for *relief* (emotion intensity 3). If participants made a mistake and tried to move forward, a pop-up window guided them to the correct responses. This manipulation check ensured that participants understood the task.

In the actual task, participants were presented with 12 colour terms (not colour patches): *red, orange, yellow, green, blue, turquoise, purple, pink, brown, black, grey* and *white* (see Table S 4 for the colour terms in all languages). Colour terms appeared one at a time above the GEW in randomized order. For each colour term, participants could select any number of the emotion concepts they thought were associated with the given colour term, or indicate none. They rated the intensity of each chosen emotion (Figure 2.2). On average, participants associated 3.05 emotion concepts with a colour term (*95% CI* = [3.03 – 3.08]; range = 2.25 – 3.84, see Table S 5).

After evaluating the 12 colour terms, participants completed a demographic questionnaire in which they reported their age, sex, colour blindness, importance of colour in their life, country of origin, country of residence, native language, and fluency of the language in which they completed the colour-emotion survey. Participants could select the "do not want to answer" option for any of the demographic questions. On the final page, participants were thanked and received results from a previous, related study in a graphic form. We provided an e-mail address for future contact. The survey took 31 minutes on average to complete for the current sample.

2.4.3. Data preparation

We applied the following inclusion and exclusion criteria to clean the data. We included participants who i) finished the survey, ii) completed the survey in their native language, and iii) this language was the official language of their country of origin. Taking Norway as an example, we included native Norwegian speakers who completed the survey in Norwegian (Bokmål) and their country of origin was Norway. An exception was made for participants from Nigeria, who completed the survey in English (national language). Nigerian participants had high English proficiency levels (M = 7.02, SD = .29, out of 8; see Table S 1 for other languages and countries). As we stated above, we excluded participants who might have been colour-blind by self-report (i.e., responded "yes", "do not know", or "do not want to answer" to the question "Do you have trouble seeing colours?"). There were 285 (5.8%) potentially colour-blind participants across all the nations.

2.4.4. Statistical Analyses

With 20 emotion concepts and 12 colour terms, we obtained 240 ratings of colour-emotion associations per participant. From these associations, we extracted two dependent variables. The first dependent variable was the **probability** of colour-emotion associations. The second dependent variable was **emotion intensity** (see below). The alpha level was set to .050 for all statistical analyses. Statistical analyses were performed and graphs created with SPSS v.25 and R Studio v. 1.1.4 (R version 3.4.0).

Global Probabilities

To evaluate the probability of colour-emotion associations, we assessed which emotion(s) are associated with each colour term without considering emotion intensity. To this end, all selected emotion associations were coded as 1 (regardless of intensity), and all non-selected emotion associations were coded as 0. We used a Bayesian method to estimate probabilities of each emotion being associated with each colour term (see section *Bayesian probabilities* in *Supplementary material*). We used the mean estimated probabilities of all participants for each colour-emotion pair to construct a global matrix of colour-emotion association probabilities (12 $\times$ 20; Figure 2.3). The same procedure was repeated for each of the 30 nations separately to obtain mean probabilities of associating every emotion with every colour term in each of the 30 nations (see 30 nation-specific colour-emotion association matrices in Table S 6). We used nation-specific matrices for further cross-cultural comparisons.

Cultural Probabilities and Their Comparisons

We first determined the degrees of similarity between nation-specific patterns of colour-emotion associations and the global pattern of colour-emotion associations – *nation-to-global pattern similarity*. The underlying values were Bayesian probabilities. The degrees of similarity were calculated by computing Pearson's correlations between the 12 $\times$ 20 colour-emotion association probabilities of each nation (nation-specific matrix) and the corresponding global 12 $\times$ 20 colour-emotion association probabilities (global matrix without that nation). The global probabilities were always based on data from 29 nations, that is, all nations but the nation of comparison. These 30 global matrices including the data from 29 nations correlated from .9983 to .9993 with the global matrix including the data from all 30 nations. Hence, no single nation unduly influenced the global pattern. See the full list of nation-specific and global matrices in Table S 6. Next, we estimated *nation-to-nation pattern similarity* by correlating all nation-specific matrices with each other (900 matrix correlations, Table S 7). We also looked at the effects of sex (Table S 8) and age (Table S 9), reported in the *Results* sub-section *Socio-demographic factors*. Finally, we repeated the pattern similarity analyses per colour term. That is, we correlated nation-specific patterns of colour-emotion association probabilities with global patterns excluding that nation for each colour term (e.g., nation-specific pattern of *red* vs. global pattern of *red,* excluding that nation; Table S 10). In all of these comparisons, a score of 1.0 indicates perfect colour-emotion association pattern similarity, while a score of 0.0 indicates complete colour-emotion association pattern dissimilarity.

In addition to colour-emotion association pattern similarity, we calculated the average probabilities of associating any colour with any emotion – *colour-emotion association average probability*. The nation-specific colour-emotion association average probability was calculated by averaging all the 240 Bayesian probabilities of colour-emotion associations of each nation. The unweighted global colour-emotion association average probability was calculated by averaging all nation-specific colour-emotion association average probabilities (global average probability score = .161, *95% CI* = [.150-.174]). We compared the global colour-emotion association average probability with nation-specific colour-emotion association average probabilities using one-sample *t*-tests. To account for multiple comparisons, *p*-values were FDR corrected, using $q = 0.05$ as threshold. As in the pattern similarity analyses, we repeated the comparisons per colour term as well as for sex and age (see the *Results* sub-section *Socio-demographic factors*). A colour-emotion association average probability score of 1.0 indicates that all colour terms were associated with all emotion concepts, while a score of 0.0 indicates that no colour term was associated with any emotion concept.

The emotion intensity variable provides information about the average intensity of all emotions associated with each colour term. To calculate *emotion intensity similarities*, we took all emotion concepts associated with a given colour term (previously coded as 1) by a given participant and averaged the intensities assigned to these emotions. Emotion intensities are reported per colour term and not per colour-emotion association. They varied from 1 (weak) to 5 (intense), unless no emotion was chosen for a given colour term (coded as missing value). We had 12 emotion intensity scores per participant (one score per colour term) and compared these scores across nations. We computed Pearson's correlations between the 12 emotion intensity scores of each nation and the corresponding global emotion intensity scores, each time leaving out that nation, when calculating nation-to-global emotion intensity similarities (see Table S 11). The resulting 29 global emotion intensity matrices including the data from 29 nations correlated from 0.9967 to 0.9999 with the global emotion intensity matrix including the data from all 30 nations. Hence, no single nation unduly influenced the global pattern. An emotion intensity similarity score of 1.0 indicates perfect emotion intensity pattern similarity, while a score of 0.0 indicates complete pattern dissimilarity.

Multivariate Pattern Classification

We used a supervised machine learning approach to predict the nation of each participant from his or her set of 240 ratings of colour-emotion association (also see, Jonauskaite, Wicker, et al., 2019). The accuracy of the classifier provides a quantitative measure of nation-specificity in colour-emotion associations. If the accuracy is equal to chance, this indicates an absence of nation-specificity in the colour-emotion associations (i.e., perfect universality). In contrast, high accuracy indicates a high degree of nation-specificity. For details of the classifier algorithm, fitting and evaluation, see *Multivariate pattern classification* in *Supplementary material.*

A quantitative measure of the similarity between a pair of nations in terms of their colour-emotion associations can be readily computed from the classifiers' confusion matrix, based on the assumption that nations that are more similar will be more frequently confused by the classifier than nations that are less similar. We used Luce's biased choice model (Eq. 5 in Luce, 1963) to estimate similarity values for each pair of nations from the confusion matrix. By convention, a similarity value between a nation and itself is set to 1.0 (representing maximum similarity), while a similarity value of 0.0 means that the two nations are completely dissimilar. The estimated similarity values are displayed in Figure S 1.

Linguistic and Geographic Distances

In addition to assessing cultural similarities, we tested whether two factors – linguistic distance and geographic distance – explain part of the similarity between the colour-emotion associations of different nations. We extracted linguistic distances for each nation-nation pair from Jäger (2018) (see *Linguistic distances* in *Supplementary Material* for language codes). These distances are suggested to capture phylogenetic distances that quantify the degree of similarity between the languages of our nation pairs.

The linguistic distances in Jäger (2018) range from 0 to 1, with lower linguistic distance scores indicating higher linguistic similarities. In this dataset, the linguistic distances are not evenly spread across this range because there are more unrelated than related language pairs in the world. This was true in our sample of languages too. In fact, the first 25% of distances fell between 0 and .75 while the remaining 75% of distances were concentrated between .75 and .90. To make the spread more homogeneous, we transformed the original distances by raising the power. At the fourth power, the transformed linguistic distances resulted in a more homogeneous spread (quantiles at 0.00, 0.32, 0.41, 0.53, and 0.65). Jäger (2018) proposed that language pairs with distances below .7 should be considered as related. Using the transformed linguistic distances, the criterion for related languages became .24 (i.e., .7^4). From here onwards, we refer to these transformed linguistic distances as "linguistic distances" (see these linguistic distances in Table S 12).

We also calculated geographic distances for all nation pairs. We used population-weighted centres to reflect the location within each country where participants were most likely to originate. If we could not find population-weighted centres, we used the geographic coordinates of the most populated city of that nation (see Table S13). Using these centres, we calculated distances (in kilometres) on a sphere between all pairs of nations (see Table S14). In two linear regression models, we used linguistic and geographic distances to predict 1) nation-to-nation pattern similarity scores (see *Cultural probabilities and their comparisons*) and 2) Luce's similarity scores (see *Multivariate pattern classification*). We argue that comparable results using both approaches provide stronger evidence for the role of linguistic and/or geographic distance, not least because scores are extracted using very different statistical methods – correlations and multivariate pattern classification.

2.5. Results

2.5.1. Global probabilities

We determined the *global matrix* of the colour-emotion association probabilities based on the unweighted means of the estimated Bayesian probabilities for each colour-emotion pair across our 30 nations. Prominent colour-emotion associations (probabilities ≥ 0.4, based on our data) were *black* and *sadness*, *black* and *fear*, *black* and *hate*, *red* and *love*, *red* and *anger*, *pink* and *love*, *pink* and *joy*, *pink* and *pleasure*, *grey* and *sadness*, *grey* and *disappointment*, *yellow* and *joy*, *orange* and *joy*, *orange* and *amusement*, and *white* and *relief* (Figure 2.3 & Table S 6).

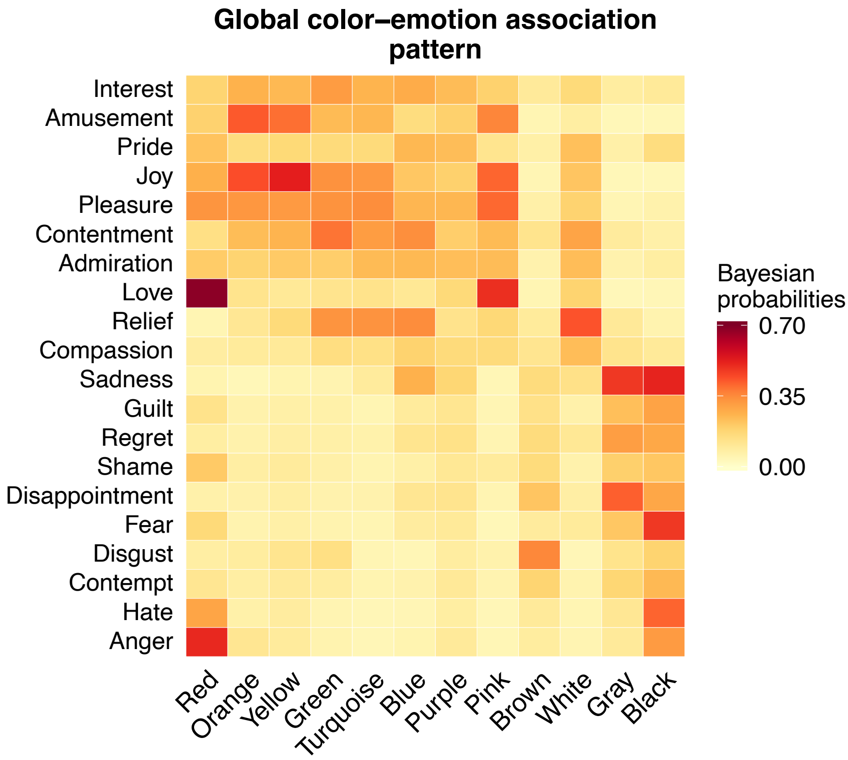


Figure 2.3. Heatmap of the unweighted averages of the colour-emotion association probabilities across our 30 nations.

More saturated orange or red indicate a higher probability of a specific colour-emotion association. The cells are not exclusive, meaning that the same participant could have contributed to none, one, or several emotion associations for a given colour term (many-to-many associations).

2.5.2. *Cultural probabilities*

Colour-Emotion Association Pattern Similarities

The nation-to-global colour-emotion association pattern similarities were high and significant for all 30 nations. The average nation-to-global pattern similarity was $r_{average}$ = .880, *95% CI* =[.857-.903], p < .001. All nation-to-global pattern similarities ranged from r = .684 (Egypt vs. global) to r = .941 (Spain vs. global), all p-values < .001, FDR corrected (Figure 2.1 & Figure 2.4 A). The high pattern similarity indicates that all individual nations associated colour terms with emotion concepts similarly to the global pattern. Nation-to-nation pattern similarities were also high and significant (*ps* < .001). They had a mean of $r_{average}$ = .781, *95%CI* = [.773-.789], and ranged from r = .501 (The Netherlands vs. Azerbaijan) to r = .951 (Switzerland vs. France), all p-values < .001, FDR corrected (see Figure S 2, Table S 7). Half of all nation-to-nation correlations fell between .738 and .839, with the median correlation of .799. Figure 2.4B shows distributions of nation-to-global and nation-to-nation pattern similarities.

Nation-to-global pattern similarities per colour term were also high. Average similarities ranged from $r_{average}$ *= .659, 95% CI =[.548-.769] (purple) to* $r_{average}$ *= .925, 95% CI =[.910-.940] (pink)* (Figure S 3 & Table S 10). Across all nations, *purple* and *yellow* had the highest variance in similarities and *pink, green, turquoise,* and *black* had the lowest variance in similarities, suggesting that associations with the former colours were the least similar while associations with the latter colours were the most similar across the 30 nations. We also observed certain nation-specific colour-emotion associations (Table S 6 & Figure S 3). For instance, Nigerians associated *red* with *fear* in addition to *love* and *anger*; Chinese associated *white* with *sadness* in addition to *relief*. Unlike other nations, Egyptians did not associate *joy* and other positive emotions with *yellow*. Greeks associated *purple* with *sadness* while other nations, on average, associated *purple* with positive emotions.

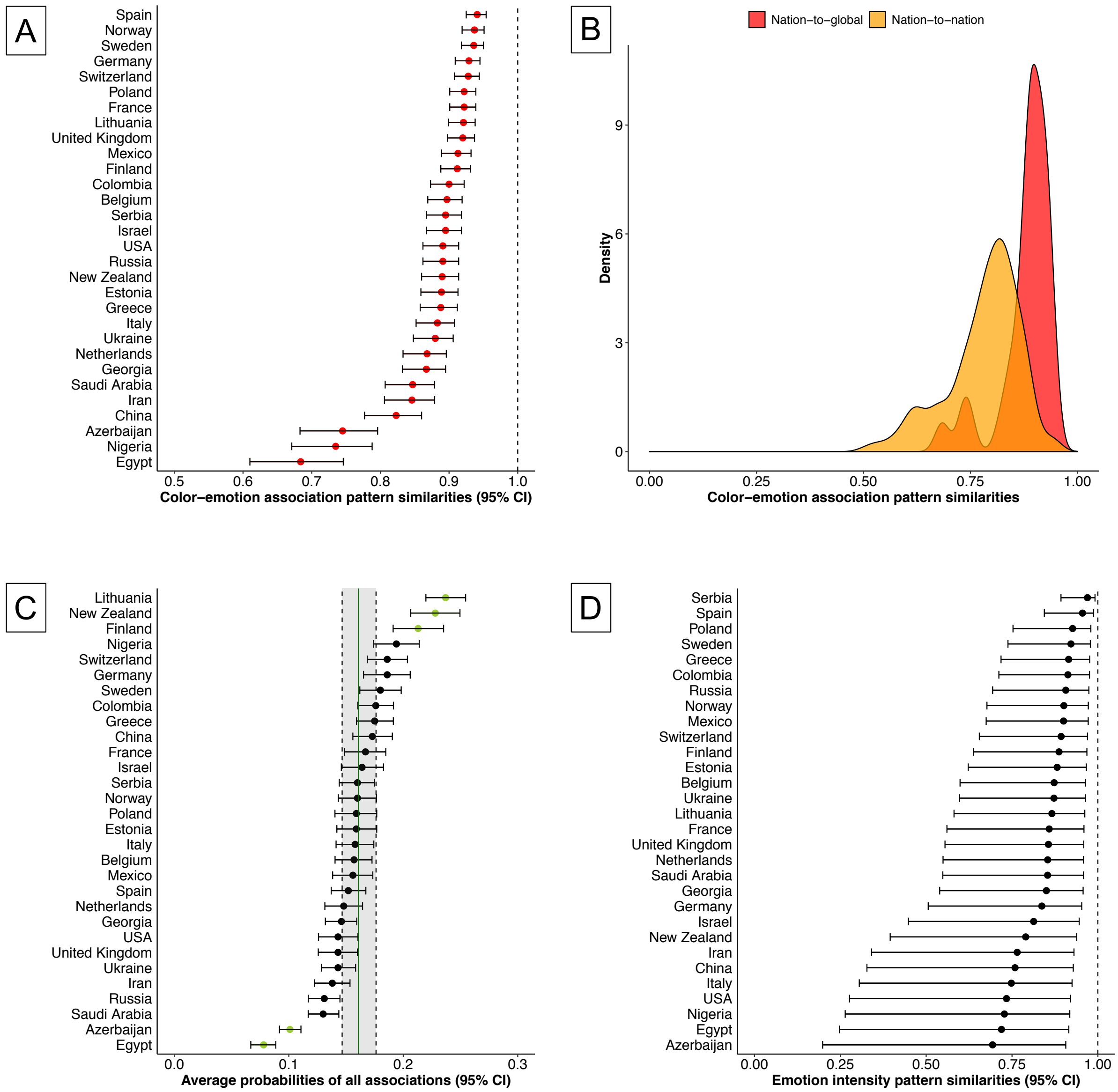


Figure 2.4. Nation comparisons.

(A) Nation-to-global colour-emotion association pattern similarities (correlations). The dotted line marks perfect pattern similarity (*r* = 1). (B) Density plots of nation-to-global and nation-to-nation colour-emotion association pattern similarities (correlations). (C) Average probabilities of all colour-emotion associations in each nation. The average probability of each nation was compared to the global average probability, which is the unweighted average of all average probabilities (dark green line; grey area = *95% CI*). Nations marked in green are significantly different from the global average probability, after FDR correction. A higher score indicates a higher probability of associating any colour term with any emotion concept. (D) Nation-to-global emotion intensity pattern similarities (correlations). The dotted line marks perfect pattern similarity (*r* = 1).

Average Probabilities of Colour-Emotion Associations

One-sample *t*-tests showed that the colour-emotion association average probabilities were not significantly different from the global average colour-emotion association probability in 25 out of 30 nations (Figure 2.4 C), $ps > .604$. Only five nations differed significantly from the global average colour-emotion association probability. Relative to the global average probability, participants from Finland, Lithuania, and New Zealand were significantly more likely while participants from Azerbaijan and Egypt were significantly less likely to associate colour terms with emotion concepts, $ps < .005$, FDR corrected (Figure 2.4 C, nations in green). When visually inspecting colour-emotion association average probabilities per colour term (Figure S 4), we found that, in every nation, *red* and *black* had the highest and *brown* the lowest average probability of being associated with any emotion concept.

Emotion Intensity Pattern Similarities

Emotion intensity pattern similarities were high and significant for all 30 nations. The average nation-to-global emotion intensity similarity was $r_{average} = .709$, *95% CI* = [.666-.752], $p < .001$, and ranged from $r = .693$ (Azerbaijan vs. global) to $r = .970$ (Serbia vs. global), $ps \leq .012$, FDR corrected (Figure 2.4 D).

2.5.3. Multivariate Pattern Classification

The machine learning classifier correctly predicted the nation for 34.4% of the participants, area under the receiver operating characteristic curve (AUC) = 0.85. This proportion correctly classified instances well above the random guessing rate of 9.7% that can be obtained by always choosing the nation contained most frequently in our data set (Azerbaijan). The AUC of 0.85 was also considerably higher than the AUC for the randomly permuted data sets (0.51). Thus, the classifier performance demonstrates a systematic amount of nation-specificity in colour-emotion associations. The confusion matrix (Figure 2.5) shows that participants from Nigeria were the easiest to predict (true positive rate TPR = .811) while participants from Spain were the most difficult to predict (TPR = .071).

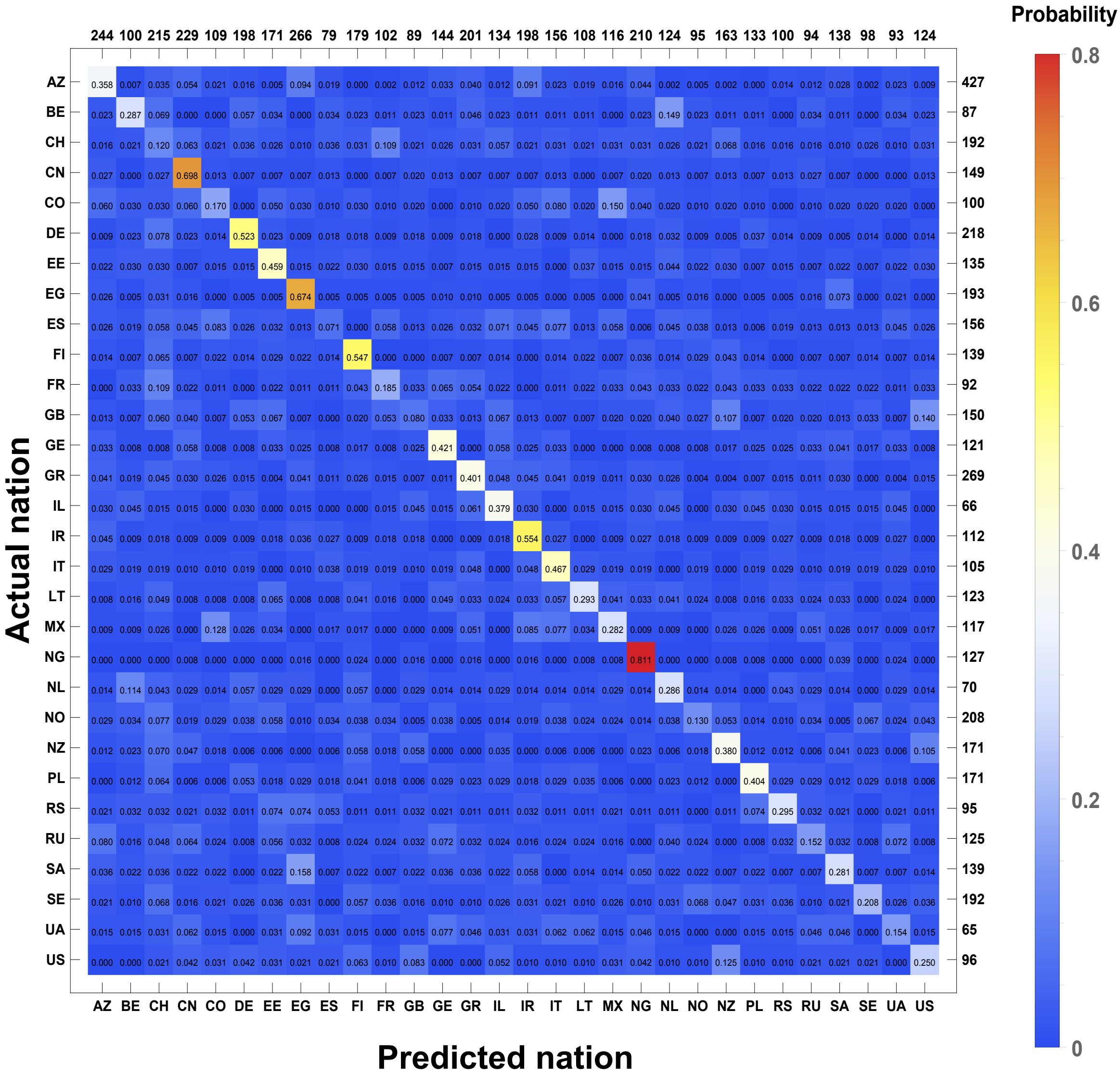


Figure 2.5. Confusion matrix for the prediction of the participants' nation (machine learning, multivariate pattern classification approach).

Rows represent the actual and columns the predicted nations, respectively (Table S 1 for nation codes). Cells represent the probability that participants originating from the nations specified in rows were classified by the machine learning algorithm as originating from the nations specified in columns, based on their individual 240 colour-emotion associations. Thus, proportions on the main diagonal represent the true positive rate, or recall. The numbers on the right-hand side represent the absolute frequency of participants originating from a given nation. The numbers on the top represent the absolute frequency of participants predicted to originate from a given nation.

2.5.4. Linguistic and Geographic Distances

We fitted a linear regression model with linguistic and geographic distance measures as predictors of nation-to-nation colour-emotion association pattern similarity scores, once with and once without the interaction between the two distance measures. The inclusion of the interaction did not improve the model ($p = .389$). Therefore, we report the model without the interaction term. The model was overall significant, $F(2, 432) = 39.9$, $p < .001$, and explained 15.2% of variance (adjusted R^2). A shorter linguistic distance, $\beta = -0.37$, $p < .001$, and a shorter geographic distance, $\beta = -0.13$, $p = .003$, both predicted higher nation-to-nation colour-emotion association pattern similarity scores (Fig 6 A&B).

The analogous linear regression model with linguistic and geographic distances as predictors of Luce's similarity scores in multivariate pattern classification was also significant, $F(2, 432) = 37.4$, $p < .001$. The model explained 14.4% of variance (adjusted R^2). Again, shorter linguistic, $\beta = -0.36$, $p < .001$, and geographic distances, $\beta = -0.13$, $p = .003$, predicted higher Luce's similarity scores (Fig 6 C&D).

2.5.5. Socio-Demographic Factors

We examined the influence of two key socio-demographic factors – sex and age – on colour-emotion association pattern similarities and on average probabilities of colour-emotion associations. Colour-emotion association patterns of men and women were almost identical, $r = .987$; $p < .001$ (Table S 8) and there were no age-related pattern differences, $r_{range} = .901 – .991$; $ps < .001$ (Table S 9). Men and women also did not differ on their average probability of colour-emotion associations, $t(478) = 0.49$, $p = .624$ (Figure S 5A). Notably, however, age was non-linearly related with average probabilities of colour-emotion associations. A curve estimation analysis revealed that the association of age with average probabilities followed a U-shaped pattern such that the average probability gradually decreased from early adulthood, that is, from 15-20 years old to 50-60 years old, and then started increasing from 50-60 years of age onwards; $F(2, 1677) = 55.22$, $p < .001$, $R^2_{adj} = .061$ (Figure S 5). In other words, 50-60-year-old participants were the least likely to associate any colour term with any emotion concept.

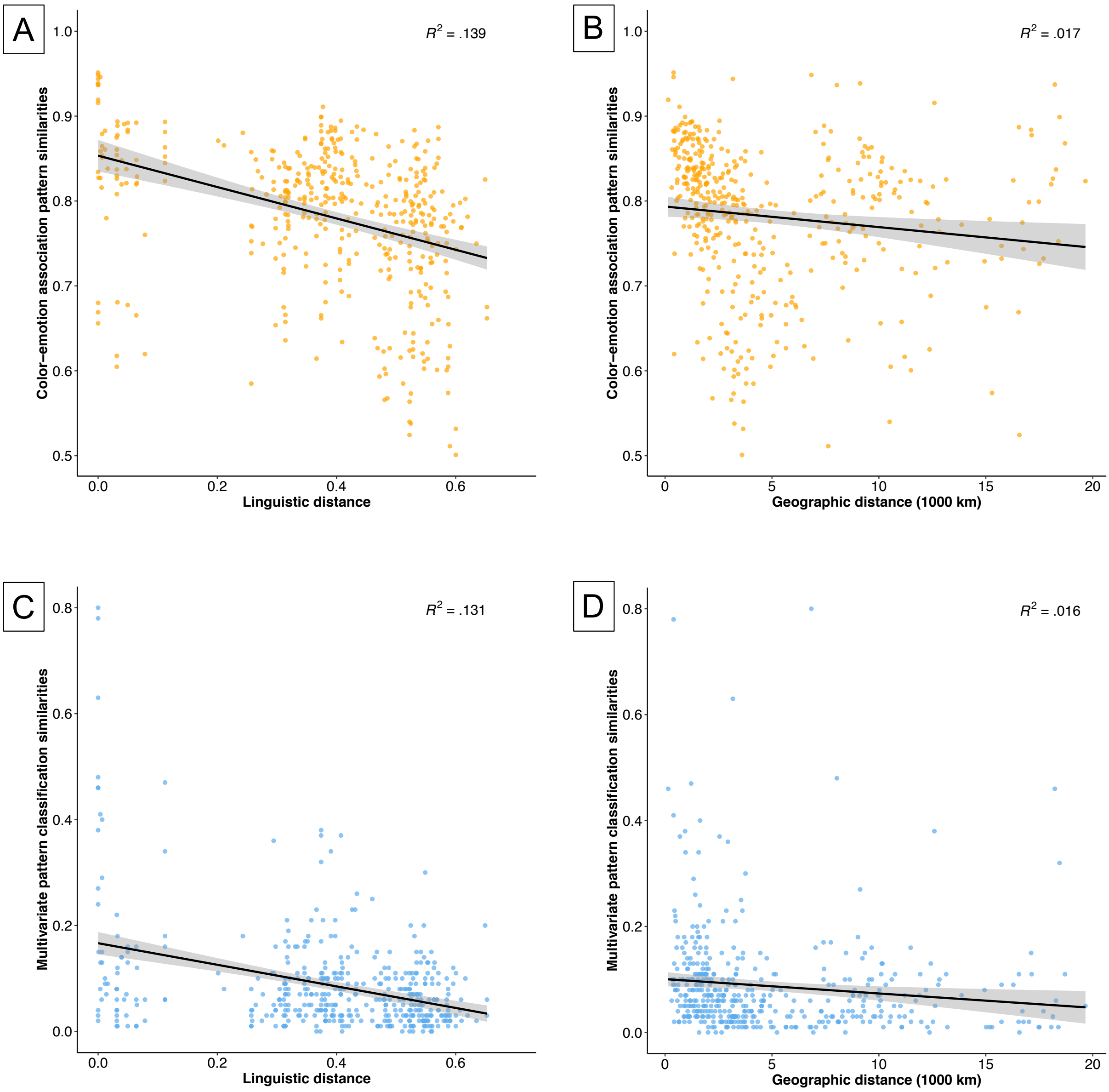


Figure 2.6. Scatter plots of linguistic and geographic distances predicting nation-to-nation similarities.

(A & B) Linguistic and geographic distances predict nation-to-nation association pattern similarities (also see, Figure 2.4 B & Figure S 2). (C & D) Linguistic and geographic distances predict estimated similarity between pairs of nations according to the Luce's biased choice model applied to the classifier confusion matrix (multivariate pattern classification similarities; also see Figure S 1). Shaded area indicates 95% CI.

2.6. Discussion

The cross-modal association of colour with emotion is a universal phenomenon. Moreover, there is global similarity in how specific emotion concepts are associated with specific colour terms, although these universal associations are modulated by geographic and linguistic factors. Across 30 nations and 22 languages on 6 continents, the pattern of colour-emotion associations in each country coincided highly with the global pattern (mean r = .88). In other words, participants from different nations shared the relative tendencies to favour certain colour-emotion associations (e.g., *love* and *anger* with *red*) over others (e.g., *shame* with *red*). Furthermore, participants from different nations agreed on which colours were the most (i.e., *black* and *red*) and the least (i.e., *brown*) emotional. Finally, they rated emotion intensities in a similar manner. Hence, we demonstrate robust agreement across 30 nations in colour-emotion associations, providing strong evidence that such associations might represent a psychological human universal (in agreement with Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Ou et al., 2018). Potential mechanisms for these universal associations may be found in a lasting shared human history, regularities in human languages and environments, and/or shared cognitive biases (C. Spence, 2011).

But beyond these global similarities, certain colour-emotion associations additionally varied locally, (also see Hupka et al., 1997; Madden et al., 2000; Soriano & Valenzuela, 2009). In particular, nations which were linguistically or geographically closer had more similar colour-emotion association patterns. Such nations were predicted with lower accuracy by the machine learning algorithm, even though the algorithm could still predict any participant's nation from the ratings of colour-emotion associations above chance level (see also, Jonauskaite, Wicker, et al., 2019). These variations might originate from cultural or linguistic differences in how emotion terms or colour terms are understood across nations (Jackson et al., 2019a). But these variations might also stem from differences in physical environments themselves. For instance, we have recently reported that exposure to sunshine modulated the degree to which yellow was perceived as a colour of joy (Jonauskaite, Abdel-Khalek, et al., 2019).

While the majority of nations did not vary in the *extent* to which colour-emotion associations were endorsed, specific variations were nevertheless observed. Finns, Lithuanians, and New

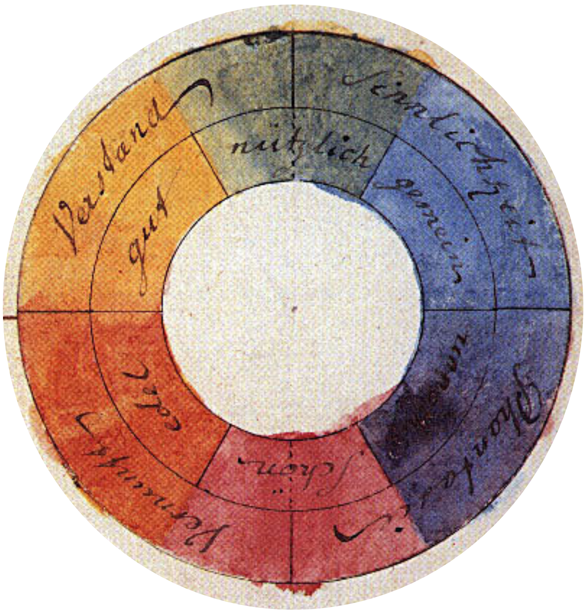
Zealanders endorsed colour-emotion associations to a greater extent, while Azerbaijanis and Egyptians did so to a lesser extent than the global average. The source of these differences requires further study. Moreover, some nations exhibited idiosyncratic colour-emotion associations. For instance, while *sadness* was universally associated with *black,* Greeks also associated it with *purple* and Chinese also associated it with *white*. Likely, these divergent colour-emotion associations reflect different cultural traditions. *White* is commonly worn at funerals in China, while Greeks occasionally wear darker shades of *purple* during mourning periods. Hence, cultural pairings of *white*, *purple*, or *black* with funerals may explain why specific colours are associated with *sadness* in some nations but not other.

In this study, we asked participants about their associations between colour terms and emotion terms, allowing us to capture the conceptual relationship between them (see also, Hupka et al., 1997; Ou et al., 2018; Palmer et al., 2013; Wexner, 1954). However, we do not know if that relationship also plays out in emotional experiences associated with colour perception. That is, people may universally associate the concepts of *red* and *anger*, but may not universally feel angry when seeing red objects. Within cultures, colours do induce specific subjective and physiological emotional responses (e.g., Wilms & Oberfeld, 2018), and similar emotion concepts are associated with colour terms and their best perceptual examples (Jonauskaite, Parraga, et al., 2020). It remains to be seen whether the direct association between colour and emotion shows the same patterns of linguistic and geographic modulation we have described here.

Our results suggest there is a universal basis for colour-emotion associations, shared by all. Numerous other human universals exist (Brown, 1991). In the domains of colour and affect, such universals include but are not limited to the shared understanding of facial emotion expressions (Ekman et al., 1969, but see Gendron et al., 2014), of emotions perceived in music (Cowen et al., 2020), of emotions expressed in human songs (Mehr et al., 2019) and shared loci of focal colours (Regier et al., 2005, but see Uusküla & Bimler, 2016). This universal foundation of colour-emotion association is further modulated by language, geography, and culture. Some might understand the modulation as evidence against universality, because colour-emotion associations were not shared at 100%. Yet, no human psychological universal is shared at 100% (Mehr et al., 2019; Norenzayan & Heine, 2005; Regier et al., 2005). Gladly, they are not. Scope for dissimilarities seems essential for dynamic adaptations to immediate and lasting changes in one's environment (Lupyan & Dale, 2016). Others might interpret our overall conclusions as evidence for a globalized world. This concern might be justified, because we mainly tested computer-literate participants who completed the survey online. Potentially, our colour-emotion associations become increasingly similar as we share more and more information globally via the Internet and other communication channels. To test the generalizability of our results, we would need further data from small-scale societies (e.g., Davidoff et al., 1999; Groyecka et al., 2019). With our current knowledge at hand, we suggest that colour-emotion associations represent a human psychological universal that likely contributes to shared communication and comprehension. Thus, next time you *feel blue* or *see red*, know the world is with you.

Chapter 3.

Feeling Blue or Seeing Red? Similar Patterns of Emotion Associations with Colour Patches and Colour Terms [17]



[17] **Jonauskaite, D.,** Parraga, C. A., Quiblier, M., & Mohr, C. (2020). Feeling blue or seeing red? Similar patterns of emotion associations with colour patches and colour terms. *I-Perception*, *11*(1), 1–24. https://doi.org/10.1177/2041669520902484

3.1. Abstract

For many, colours convey affective meaning. Popular opinion assumes that perception of colour is crucial to influence emotions. However, scientific studies test colour-emotion relationships by presenting colours as patches or terms. When using patches, researchers put great effort into colour presentation. When using terms, researchers have much less control over the colour participants think of. In this between-subjects study, we tested whether emotion associations with colour differ between terms and patches. Participants associated 20 emotion concepts, loading on valence, arousal, and power dimensions, with 12 colours presented as patches (n = 54) or terms (n = 78). We report high similarity in the pattern of associations of specific emotion concepts with terms and patches (r = .82), for all colours except *purple* (r = .-23). We also observed differences for black, which is associated with more negative emotions and of higher intensity when presented as a term than a patch. Terms and patches differed little in terms of valence, arousal, and power dimensions. Thus, results from studies on colour-emotion relationships using colour terms or patches should be largely comparable. It is possible that emotion is associated with colour concepts rather than particular perceptions or words of colour.

3.2. Introduction

Across languages and cultural traditions, we use colour to express and convey emotional states. We *feel blue, see red,* or we are *green with envy*; we wear white to weddings, black to funerals; and we give red hearts to our loved ones on Valentine's Day. It seems that colour-emotion associations are ubiquitous (e.g., Adams & Osgood, 1973; Allen & Guilford, 1936; Hupka, Zaleski, Otto, Reidl, & Tarabrina, 1997; Ou et al., 2018; Valdez & Mehrabian, 1994). One detail should, however, not be neglected: the first examples are concerned with affective colour expressions, omnipresent in language (Soriano & Valenzuela, 2009), while the remaining are concerned with colour perceptions. Actual research into colour-emotion associations have used both colour patches (e.g., Valdez & Mehrabian, 1994) and colour terms (e.g., Adams & Osgood, 1973). When using patches, great effort is put into how colours appear by controlling colour presentation (see Valdez & Mehrabian, 1994). Researchers can carefully control the three colour dimensions of hue, saturation, and lightness (Hunt & Pointer, 2011a), and test a myriad of colours. When using terms, researchers have little control over the colour participants think of. In such studies, researchers can present fewer colours and the colours are presented as terms. Considering these methodological differences, we have little *a priori* knowledge to predict whether and, if so, which colour-emotion relationships would be the same or different, when one is presented with patches or terms.

The roles of language versus perception have been considered in various theoretical frameworks. The conceptual metaphor theory emphasizes the role of language in colour-emotion associations (Lakoff & Johnson, 1999). This theory suggests that abstract concepts like affect (i.e., emotions, mood, evaluations, preferences) are metaphorically, or metonymically, linked to more concrete perceptual experiences such as colour (see also, Meier & Robinson, 2005; Soriano & Valenzuela, 2009). This link would help people to better understand and describe their affective experiences. Meier and Robinson (2005) used this framework to explain the omnipresent association between positivity and lightness, which manifests in metaphorical expressions like *bright day* and *dark thoughts* (Adams & Osgood, 1973; Lakens et al., 2013b; Meier et al., 2007; Specker et al., 2018). Meier and Robinson (2005) additionally argued that such metaphorical associations further reinforce these links across time, through language and cultural learning. At some point, the metaphors might function independently from the original perceptual associations and so dissociate language and perception (e.g., there is no clear perceptual base for expressions like *green with envy*, *feeling blue*, *yellow-bellied*).

Other frameworks are less readily apt to explain colour-emotion associations through affective metaphors (e.g., colour preferences are largely established through past perceptual experience in the Ecological Valence Theory; Palmer & Schloss, 2010). If we take the example of *yellow*[18] and *joy*, this association is widely spread (Burkitt & Sheppard, 2014; Dael et al., 2016; Jonauskaite, Althaus, et al., 2019; Kaya & Epps, 2004; Lindborg & Friberg, 2015; Sutton & Altarriba, 2016b), but has no equivalent metaphorical expression, at least not in English, German, French, Lithuanian, Dutch, or Spanish. Rather, yellow is metaphorically associated with negative emotions in different languages (e.g., *yellow-bellied* – to be cowardly or easily scared; *Gelb vor Neid sein* – to be envious, *rire jaune* – forced laughter to hide embarrassment). Similarly, despite the expression *feeling blue* signifying *sadness* in English*, blue* has been repeatedly associated with positive emotions (Adams & Osgood, 1973; Kaya & Epps, 2004; Valdez & Mehrabian, 1994; Wexner, 1954) and is generally a liked colour (Eysenck, 1941; Jonauskaite, Dael, et al., 2019; Palmer & Schloss, 2010) in English and non-English speaking countries. In such cases, visual colour perception may play a more important role than language. These associations might be rooted in repeated perceptual associations between a colour and an emotional situation, such as feeling joyful when the sun is shining or feeling good when looking at clear blue water. Such propositions have been made to explain colour preferences (Ecological Valence Theory, Palmer & Schloss, 2010) and various cross-modal relationships (structural or statistical correspondence, C. Spence, 2011).

When appreciating the implications of the various frameworks, we would have to expect that certain colour-emotion associations might be more strongly reinforced by the linguistic system and colour metaphors (e.g., the associations between *blue* and *sadness*, *yellow* and *negative emotions*) and others through the perceptual system (e.g., the associations between *yellow* and

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[18] Colour terms in Italics (e.g., *yellow*) refer to both a colour patch (i.e., a yellow perceptual stimulus) and a colour term (i.e., *jaune* being yellow in French, because we conducted the current study in French).

joy, *blue* and *positive emotions*). In the former case, the actual colour presentation might play a more important role, while in the latter case, colour presentation might play a less important role. Moreover, there might be colour-emotion associations reinforced by both systems. For instance, the metaphorical expression *seeing red* associates *red* with feelings of *anger*, which would indicate a linguistic influence. Nonetheless, when one gets angry, blood rushes to the face (Benitez-Quiroz et al., 2018), and so the perception of red faces in an angry situation might further strengthen the association between *red* and *anger*.

One possible approach for investigating which system, perceptual or linguistic, reinforces colour-emotion associations to a greater extent, is to compare emotion associations with colour presented as patches (i.e., perceptual stimuli) versus as terms (i.e., linguistic stimuli). Despite the large body of empirical studies on colour-emotion associations, few studies have compared these methods directly (see Wang, Shu, & Mo, 2014 for a notable exception). More commonly, researchers worked separately with either colour patches (Allen & Guilford, 1936; D'Andrade & Egan, 1974; Fugate & Franco, 2019; Hanada, 2018; Kaya & Epps, 2004; Manav, 2007; Palmer, Schloss, Xu, et al., 2013; Valdez & Mehrabian, 1994) or colour terms (Adams & Osgood, 1973; Hupka et al., 1997; Soriano & Valenzuela, 2009; Sutton & Altarriba, 2016b). Researchers working with perceptual colour stimuli have criticised research studies that used linguistic colour stimuli on the basis of vagueness and imprecision (e.g., Fugate & Franco, 2019; Valdez & Mehrabian, 1994). In other words, when presenting linguistic stimuli, unlike when presenting perceptual stimuli, one does not know the exact colour (how light, how saturated) participants visualised. Thus, it is unclear if emotions are attached to particular physical properties of colours, particular colour terms, or instead to colour concepts (i.e., abstract representations of colour combining colour perceptions with colour terms).

Furthermore, different methodologies of colour assessment might tap into different associative mechanisms. For instance, Wang and colleagues (2014) studied which colour-emotion associations are "natural" (i.e., arise due to perceptual pairing) and which are "social" (i.e., arise due to linguistic and cultural pairing) in Chinese participants. They tested implicit valence associations with colour terms and colour patches (*red* and *blue*). The authors demonstrated that *red* was evaluated both positively and negatively when presented as a patch. When *red* was presented as a term, it was evaluated exclusively positively. The authors suggested that the association between *red* and negative emotions (e.g., *anger*) is “natural”. Thus, it is present when a *red* patch is perceived. When *red* is treated linguistically, however, such pairing may be overshadowed by the exclusively positive connotations of *red* in Chinese culture (i.e., good fortune, success, beauty, joy, etc.; Toulson, 2013) – the “social” associations. Hence, to obtain a more complete picture, emotion associations should be tested with both colour terms and patches.

In the current study, we investigated the extent to which colour-emotion associations are comparable between colour patches and colour terms by asking participants to associate as many or as few emotion concepts (Geneva Emotion Wheel; Scherer, 2005; Scherer, Shuman, Fontaine, & Soriano, 2013) with 12 colours. The emotion concepts differentially loaded on the emotion dimensions of *valence* (positive-negative), *arousal* (high arousal-low arousal), and *power* (strong-weak; Fontaine, Scherer, Roesch, & Ellsworth, 2007). Thus, we were able to analyse colour associations with specific emotions and emotion dimensions. We also tested emotion intensity. Crucially, one group of participants associated emotion concepts with colour terms (Experiment 1) while the other group associated emotion concepts with colour patches (Experiment 2). We chose the 11 basic colour terms in French plus *turquoise* for the term condition and focal colours that best matched each term for the patch condition (Lindsey & Brown, 2014). The focal colours are representative members of colour categories (Abbott et al., 2016), thus participants were likely to imagine focal colours when presented with colour terms. We expected some degree of dissimilarity between colour terms and colour patches, especially for colours that might have divergent meanings as a term and as a patch (e.g., *blue*, *yellow*).

3.3. Materials and Method

3.3.1. Participants

We recruited 132 first year university students (23 males) with a mean age of 20.52 years (*95% CI* = [20.21, 20.82]). Seventy-eight participants (15 male) took part in Experiment 1 (M_{age} = 21.19, *95%* CI_{age} = [20.88, 21.51], range: 19-24); and a new group of 54 participants (8 males) took part in Experiment 2 (M_{age} = 19.60, *95%* CI_{age} = [19.10, 20.01], range: 18-26). An independent samples *t*-test showed that participants in Experiment 1 (M = 21.19, SD = 1.40) were slightly older than in Experiment 2 (M = 19.56, SD = 1.66), $t(130) = 6.13$, $p < .001$, $d = 1.06$. This difference occurred because participants in Experiment 1 participated at the end of the academic year, while participants in Experiment 2 participated at the beginning of another academic year. The gender distribution was comparable in both experiments, $\chi^2(1) = .432$, p = .51, V = .057.

We performed a sample size power analysis (Mayr et al., 2007) for a 2 x 12 mixed-design ANOVA based on the number of emotions (*broadness*). This analysis suggested that at an alpha level of .050 and a beta level of .950, and assuming a correlation between repeated measures of .5 and epsilon of 1, the total sample size of 54 is sufficient to detect a medium effect size of .25. We set 27 (i.e., 54/2) as a minimum number of participants for each colour presentation condition and recruited participants over two months (April-May) for Experiment 1 and two months (October-November) for Experiment 2. We included all participants who volunteered in this time window (total N = 173; n = 98 in Experiment 1, n = 75 in Experiment 2).

We subsequently excluded participants in case of self-reported (n = 3 in Experiment 1) or tested (n = 1 in Experiment 2; Ishihara, 1993) colour blindness, or who were not native French speakers (n = 13 in Experiment 1; n = 20 in Experiment 2). We recruited participants from the same student pool, but coming from different academic years. Consequently, participants' age, gender, level of education, and native language were matched between the two experiments. Finally, since the data for Experiment 1 were Internet-based, we excluded participants who were too quick or too slow (i.e., took ≤ 3 or ≥ 90 min; n = 4), or did not show minimal engagement with the experiment (i.e., spent ≤ 20 s on the first four colour terms; *n* = 0; see also, Jonauskaite, Dael, et al., 2019)

Participation was voluntary and was rewarded with course credit. Both experiments were conducted in accordance with the principles expressed in the Declaration of Helsinki (World Medical Association, 2013). No specific ethical clearance was received for this study, as the law of Canton of Vaud, Switzerland, did not require it.

3.3.2. Colour Stimuli

We used 12 colour stimuli – *red, orange, yellow, green, turquoise, blue, purple, pink, brown, white, grey,* and *black* – labelling the principal colour categories (Biggam, 2012a). They were presented as colour terms written in black ink in French (Experiment 1) or as colour patches (Experiment 2). *Turquoise* covers the blue-green range and the remaining 11 stimuli represent French basic colour categories (Morgan, 1993; Table S 15). For patches, we displayed the best exemplars of each colour category (i.e., focal colours, Table 3.1, Lindsey & Brown, 2014, which are largely universally recognised, Regier, Kay, & Cook, 2005).

Table 3.1. Colour stimuli used for colour terms and colour patches conditions.

Identical stimuli were used in studies reported in Chapters 3 and 5. Munsell values for colour patches taken from Lindsey & Brown (2014). The last columns show the CIE1931 *xyY* values for our patches.

Colour term (Experiment 1)	Colour patch (Experiment 2)					
	Munsell colour-order system			CIE1931 coordinates		
	Hue	Value	Chroma	Y (cd/m^2)	x	y
Red	5.00 R	4	14	12.00	.57	.31
Orange	5.00 YR	6	12	30.05	.51	.42
Yellow	5.00 Y	8	14	59.44	.45	.48
Green	2.50 G	5	12	20.99	.27	.50
Turquoise	7.50 BG	6	8	30.38	.22	.33
Blue	10.00 B	6	10	30.05	.20	.24
Purple	7.50 P	4	10	12.00	.31	.22
Pink	7.50 RP	7	8	43.07	.37	.31
Brown	7.50 YR	3	6	6.55	.49	.42
White	10.00 RP	9.5	0	90.01	.31	.33
Grey	10.00 RP	6	0	30.05	.31	.33
Black	10.00 RP	1.5	0	2.02	.31	.33
Grey (background)	10.00 RP	5	0	18.58	.31	.32

3.3.3. Emotion Assessment

The Geneva Emotion Wheel (GEW 3.0; Figure 1.7; Scherer, 2005; Scherer et al., 2013) is a self-report measure of the feeling component of emotion. Twenty emotion concepts (Figure 1.7) are represented along the circumference of a wheel, organized around two axes – *valence,* also known as evaluation or pleasantness, (horizontal: positive vs. negative) and *power*, also known as control, dominance, or potency, (vertical: strong vs. weak). Emotion concepts similar in valence and power are placed close to each other on the GEW. Emotion concepts can further be categorised in terms of *arousal,* also known as activation, (high arousal vs. low arousal) based on complementary research studies (Fontaine, 2013; Soriano et al., 2013, Table 1.1). Circles of increasing size connect the centre of the wheel with the circumference of the wheel. These circles denote five degrees of emotion intensity, coded from 1 (smallest circle; weakest intensity) to 5 (biggest circle; strongest intensity), or 0 if no emotion is chosen (little square).

The Swiss Centre for Affective Sciences provides the validated French version of the GEW (**Table S 15**).

3.3.4. Procedure: Experiment 1 (colour terms)

Data for Experiment 1 was collected online from the first-year psychology student pool of the local university. The experiment started with an information page. Participants were informed that they expressed their consent to participate if they continued to the next page. Then, participants were explained the task and performed a manipulation check exercise indicating they understood the task. Participants were asked to correct the responses of an imaginary person (Peter) and were given feedback. During the experiment, participants saw the 12 colour terms written in black ink (Table 3.1) presented sequentially and in random order above the GEW on a neutral grey background. Participants associated one, several, or none of the GEW emotion concepts with each colour term and rated the respective emotion intensity by choosing circles of different sizes (later converted to 1-5 ratings). After the main experiment, participants provided demographic information and were debriefed. They also saw results from a previous related marketing experiment in a graphic form. Participation took on average 12.3 minutes (Figure 3.1).

We collected the current data as part of a larger on-going International Colour-Emotion Survey online (https://www2.unil.ch/onlinepsylab/colour/main.php; Mohr, Jonauskaite, Dan-Glauser, Uusküla, & Dael, 2018). Given the continuous nature of the survey, we reported part of these data in our study on gendered colours (Jonauskaite, Dael, et al., 2019, Study 3). Procedure: Experiment 2 (colour patches)

3.3.5. Procedure: Experiment 2 (colour patches)

Data for Experiment 2 was collected in the laboratory from the first-year psychology student pool. Upon arrival, participants signed a written informed consent form. We next used a paper-version of Ishihara (Ishihara, 1993) colour blindness test to assess participants' colour vision. Afterwards, participants were invited to individual testing rooms, which were dark and illuminated only by a computer monitor. Participants were presented with a colour patch (15° x 15° viewing angle) on a neutral grey background (see Table 3.1) for a minimum of 5 seconds and instructed to focus on the colour patch. Participants chose when to move to the subsequent page. There, in analogy to Experiment 1, they associated one, several, or none of the GEW concepts with the target colour patch and rated the intensity of each associated emotion concept. While associating emotions, participants could see the target colour on small GEW squares as well as on the chosen intensity circles (Figure 3.1B. Experiment 2). There were three trial colour patches at the beginning of the experiment, with 12 total experimental colour patches presented in randomised order (Table 3.1, values adapted for each monitor, see *Apparatus*). We collected these data in the laboratory to ensure accurate colour presentation. Experimenters were available for questions at any point during the experiment. After the main experiment, participants provided demographic information on a paper questionnaire and completed another unrelated experiment, not reported here (choosing focal colours). Finally, they were debriefed. The experiment took approximately 15 minutes (Figure 3.1).

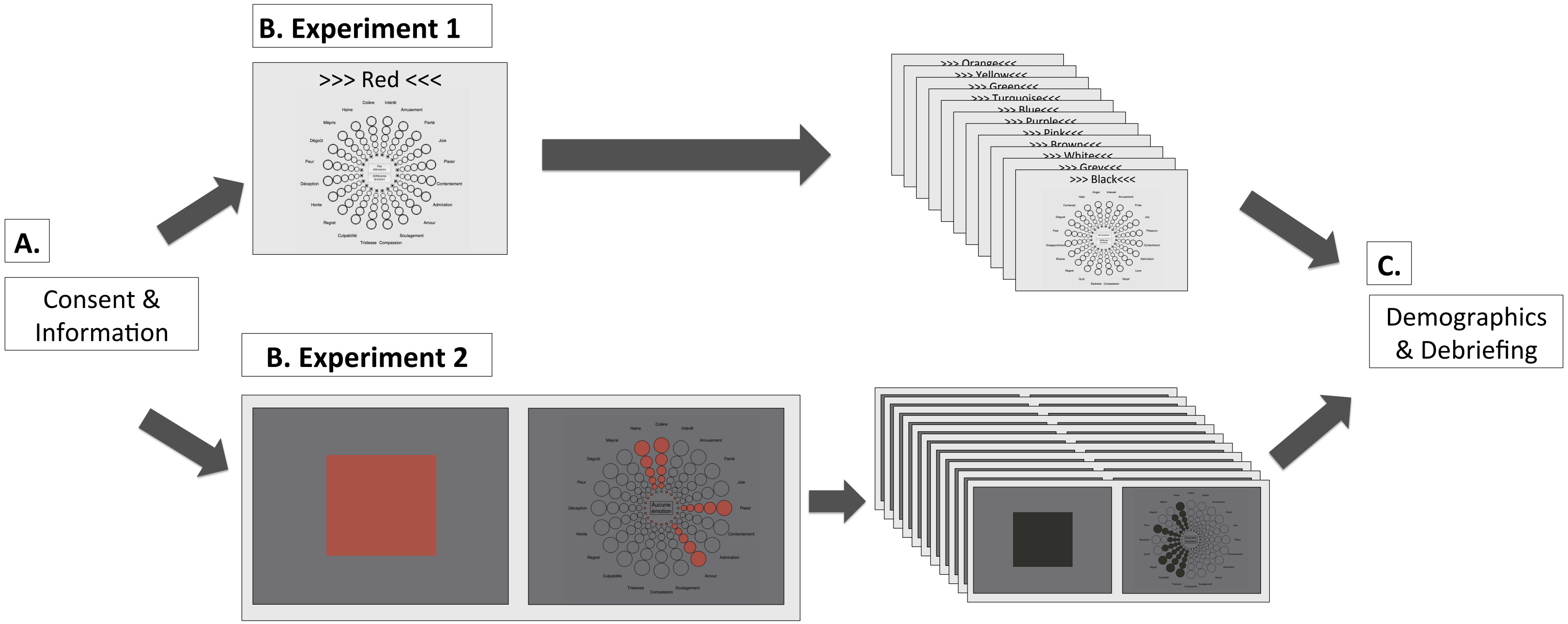


Figure 3.1. Procedure for Experiments 1 and 2 in Chapter 3.

(A) Participants received written study information and signed informed consent. (B) Main experiment. In Experiment 1, participants saw 12 colour terms in randomised order. They associated colour terms with one, several, or none of the Geneva Emotion Wheel (GEW) emotion concepts (see *Emotion assessment* and Figure 1.7 for enlarged GEW). In Experiment 2, participants saw 12 colour patches in randomised order. They associated colour patches with one, several, or none of the GEW emotion concepts on the subsequent screen. Here, they saw the small GEW squares as well as the GEW rays of chosen emotion concepts presented in the colour they were currently evaluating. (C) Participants answered demographic questions and were debriefed.

3.3.6. Apparatus

The task was performed on four similar monitors (Colour Edge CG243W 24.1" Widescreen LCD display), which were linearized with an in-built sequence before each session. We used the Konica Minolta CS-100A chroma meter to measure the parameters of red, green, and blue guns of each monitor. We report here the white points of the monitors (monitor #1: .318, .334, 73; monitor #2: .325, .340, 113; monitor #3: .321, .336, 109; monitor #4: .318, .323, 128) in CIE *xyY* colour space. Although the four monitors had substantially different luminance values for the white points, these differences should not affect our study given that colour presentation was calculated for each monitor separately. Monitor #1 could not produce a luminance value large enough to represent the white patch (see Table 1) and thus it displayed a slightly darker version. However, observers adapted to this maximum value and did not perceive any difference. The gamma curves were estimated from luminance increments of each of the three guns using a standard protocol (Brainard et al., 2002). The measured primaries in CIE *xyY* of monitor #1 were Red (*R*) = (.697, .300, 18.9), Green (*G*) = (.189, .698, 50.9), and Blue (*B*) = (.141, .026, 2.13), monitor #2 – *R* = (.696, .301, 29.6), *G* = (.192, .701, 78.9), and *B* = (.141, .026, 3.17), monitor #3 – *R* = (.695, .301, 28.7), *G* = (0.191, 0.699, 76.8), and *B* = (.141, .028, 3.30), and monitor #4 – *R* = (.696, .301, 34.9), *G* = (.188, .694, 89.5), and *B* = (.141, .027, 4.25). These measurements were then used to convert colour values from monitor-independent xyY system to monitor-dependent RGB system and display them in each screen. This step was necessary in order to keep the photometric characteristics of colour stimuli constant across monitors. Viewing was unrestrained and the viewing distance was approximately 70 cm.

3.3.7. Design and Data Analysis

We employed a mixed design to establish which emotions were associated with which colours (terms and patches together; within-subjects design) and to compare the emotion associations between colour terms and patches (between-subjects design). The independent variables (IVs) were 1) colour presentation mode (between-subjects; colour term or colour patch), 2) colour (within-subjects, 12 levels, see *Colour stimuli*), and 3) emotion (within-subjects, 20 levels, see *Emotion assessment*) or emotion dimensions of valence, arousal, and power (within-subjects, 2 levels, see below).

Specific Emotions

We started the analyses by investigating the specific emotion concepts associated with colours. We calculated the proportion of participants who associated a specific colour with a specific emotion concept by dividing the number of participants who chose each emotion concept for each colour by the total number of participants. The proportion of participants was calculated for each colour presentation condition separately as well as both conditions together. The proportion was the first dependent variable (DV1). DV1 varied from 0 (very unlikely association, no one chose it) to 1 (very likely association, everyone chose it).

We identified the most and least prominent colour-emotion associations with a Two-Step auto-cluster analysis using Schwarz's Bayesian Criterion (Bacher et al., 2004) on the proportion values of terms and patches together (DV1). To compare the *pattern* of emotion associations, we created two 12 x 20 (colours x emotions) representation matrices using the proportion values. Then, we employed representation similarity analyses based on Pearson matrix-to-matrix correlations (Kriegeskorte, 2008) to compare the colour term matrix (12 x 20) with the colour patch matrix (12 x 20), also known as a Pattern Similarity Index (PSI). PSI reflects the degree of similarity in the pattern of colour-emotion associations across terms and patches. A PSI score of 1 indicates perfect pattern similarity, and a PSI score of 0 indicates complete pattern dissimilarity. Furthermore, to compare the similarity of emotion associations between terms and patches for each colour, we calculated PSI_{colour}. PSI_{colour} was estimated per colour using Pearson correlations (12 correlations, each time 1 x 20 colour term vector correlated to 1 x 20 colour patch vector).

To test whether the *proportion* of participants endorsing an association differed between terms and patches, we used mixed-design 2 x 240 ANOVA on proportion values, which accounted for the repeated-measures design. This test indicated whether emotion associations were overall more likely for terms or patches. To identify the source of any dissimilarity, we used Fisher's exact tests (Fisher, 1922) to compare the proportion of participants endorsing a particular colour-emotion association (yes/no; n = 240) for terms and patches.

Emotion Dimensions

We derived emotion dimensions associated with colours from the number of emotion concepts associated with each colour. For each colour, we counted how many positive and negative (*valence*), high and low arousal (*arousal*), and strong and weak (*power*) emotion concepts each participant chose (Table 1.1). The number of emotions indicated the *broadness* of associations and was our second dependent variable (DV2). DV2 varied from 0 to 10 for each level of valence, arousal, and power. We conducted a mixed-design 2 x 2 x 12 multivariate analysis of variance (MANOVA) model with broadness of valence, arousal, and power as dependent variables, and levels of emotion dimensions (positive-negative, high-low arousal, strong-weak), colour presentation mode and colour as independent variables.

Emotion Intensity

The third dependent variable (DV3) – *emotion intensity* – was calculated by averaging intensity ratings assigned to emotion concepts associated with each colour. Emotion intensity varied from 1 (weak) to 5 (strong), unless no emotion concept was chosen (coded as missing value). Series of independent-samples *t*-tests compared *emotion intensity* ratings (DV3) between terms and patches overall, and for each colour separately. We used *t*-tests to preserve statistical power due to missing values.

Across the statistical tests, where appropriate, we controlled familywise error (Type I error) using False Discovery Rate (FDR) correction and marked the corrected *p*-values as p_{FDR} (Benjamini & Hochberg, 1995). Alpha level was set at .05; all analyses were two-tailed. We performed analyses and created graphs with the R v.3.4.0 and SPSS v.25.

3.4. Results

3.4.1. Specific Emotions

Across terms and patches, the cluster analysis indicated three clusters of specific colour-emotion associations with a satisfactory goodness of fit (silhouette measure of cohesion and separation was 0.7, BIC = 64.9). Cluster 1 included prominent associations (n = 26), endorsed by many (38-73%) participants. The most prominent specific colour-emotion associations were *red-anger* (73%), *red-love* (68%), *red-hate* (51%), *red-pleasure* (39%), *orange-joy* (48%), *orange-amusement* (41%), *yellow-joy* (61%), *yellow-amusement* (44%), *turquoise-joy* (45%), *turquoise-pleasure* (41%), *blue-relief* (38%), *pink-pleasure* (63%), *pink-love* (63%), *pink-joy* (55%), *pink-amusement* (42%), *brown-disgust* (50%), *white-relief* (44%), *grey-sadness* (61%), *grey-regret* (55%), *grey-disappointment* (54%), *black-disappointment* (48%), *black-hate* (47%), *black-sadness* (45%), *black-regret* (45%), *black-fear* (45%), and *black-contempt* (43%). *Green* and *purple* had no specific emotion associations in the cluster of the most prominent associations. Cluster 2 included occasional associations (n = 77) endorsed by 17%-37% of participants (e.g., *blue-sadness, green-amusement*). Cluster 3 included rare associations (n = 137) endorsed by 2%-17% of participants (e.g., *pink-pride, blue-love, red-amusement*). We show the colour-emotion associations as proportions in Table S 16 for terms and patches together, in Table S 17 for terms, in Table S 18 for patches, and graphically in Figure 3.2.

After having established the specific colour-emotion associations, we compared the associations between terms and patches. The PSI comparing the patterns of colour-emotion associations with matrix-to-matrix correlations indicated a high degree of similarity (r = .82, R^2 = .672, p < .001) between terms and patches (Figure 3.2A: terms, Figure 3.2B: patches). This result means that similar emotions were associated with colours as terms and as patches. Furthermore, colour-specific PSI_{colour} were high (r = .79-.96, R^2 = .624-.922) for all colours except *purple* (r = -.23, R^2 = .053, p_{FDR} = .340, see Table 3.2), indicating that the similarity between terms and patches held across all colours except *purple*. The specific emotion concept associations with *purple* as a term were unrelated to those with *purple* as a patch.

When looking at the proportion of participants endorsing colour-emotion associations, the mixed-design ANOVA on the proportion values showed a main effect of presentation mode,

$F(1, 239) = 33.05$, $p < .001$, $\eta_p^2 = .121$. A higher proportion of participants endorsed emotion associations with colour terms than with colour patches. Fisher's exact tests identified that the associations between *black* and *hate*, $p_{FDR} < .001$, *OR* = 8.64, 95% *CI* = [3.59, 22.48]; *black* and *anger*, $p_{FDR} = .007$, *OR* = 5.13, 95% *CI* = [2.05, 14.26]; *black* and *regret*, $p_{FDR} = .007$, *OR* = 4.48, 95% *CI* = [1.98, 10.66]; and *black* and *sadness*, $p_{FDR} = .022$, *OR* = 3.85, 95% *CI* = [1.72, 9.00] were more often chosen when black was a term than a patch. No other comparisons were significant (see Figure 3.2C).

3.4.2. Emotion Dimensions

A mixed-design MANOVA estimating the number of emotion concepts (broadness) was overall significant; Pillai's Trace value = .55, $F(1, 130) = 160.0$, $p < .001$, $\eta_p^2 = .552$. The MANOVA indicated a main effect of colour, Pillai's Trace value = .52, $F(11, 120) = 11.70$, $p < .001$, $\eta_p^2 = .517$, demonstrating that the number of associated emotion concepts varied by colour. This effect was significant for individual mixed-design ANOVAs on valence, $F(11, 1430) = 15.62$, $p < .001$, $\eta_p^2 = .107$, arousal, $F(11, 1430) = 15.62$, $p < .001$, $\eta_p^2 = .107$, and power, $F(11, 1430) = 15.62$, $p < .001$, $\eta_p^2 = .107$. Planned deviation contrasts indicated that *red, yellow, pink* and *black* yielded a greater number and *purple*, *brown*, and *white* a smaller number of emotion concepts than average (*ps* ≤ .012; Table 3.3).

There was no main effect for colour presentation mode, Pillai's Trace value = .01, $F(1, 130) = 1.38$, $p = .242$, $\eta_p^2 = .011$. This result means that the same number of emotions, on average, was associated with terms and patches. Nonetheless, there was a significant interaction between colour and colour presentation mode, Pillai's Trace value = .27, $F(11, 120) = 3.97$, $p < .001$, $\eta_p^2 = .267$. This interaction was present for all three individual mixed-design ANOVAs on valence, $F(11, 1430) = 5.59$, $p < .001$, $\eta_p^2 = .041$, arousal, $F(11, 1430) = 5.59$, $p < .001$, $\eta_p^2 = .041$, and power, $F(11, 1430) = 5.59$, $p < .001$, $\eta_p^2 = .041$. Post-hoc comparisons revealed that a greater number of emotion concepts was associated with *black* when presented as a term than as a patch ($p_{FDR} < .001$). The term versus patch comparisons were not significant for other colours (all $ps_{FDR} \geq .30$; Table 3.3).

Table 3.2. The pattern similarity index (PSI) between colour terms and colour patches.

The PSIcolour indicates the similarity of colour-emotion association patterns between colour terms and colour patches, for each colour separately. All *p*-values are FDR corrected for multiple comparisons; *** $p < .001$, $r = 1$ suggests perfect similarity.

Colour	PSI_{colour} (*r*)
Red	.92***
Orange	.94***
Yellow	.90***
Green	.88***
Turquoise	.88***
Blue	.79***
Purple	-.23
Pink	.92***
Brown	.88***
White	.91***
Grey	.96***
Black	.81***

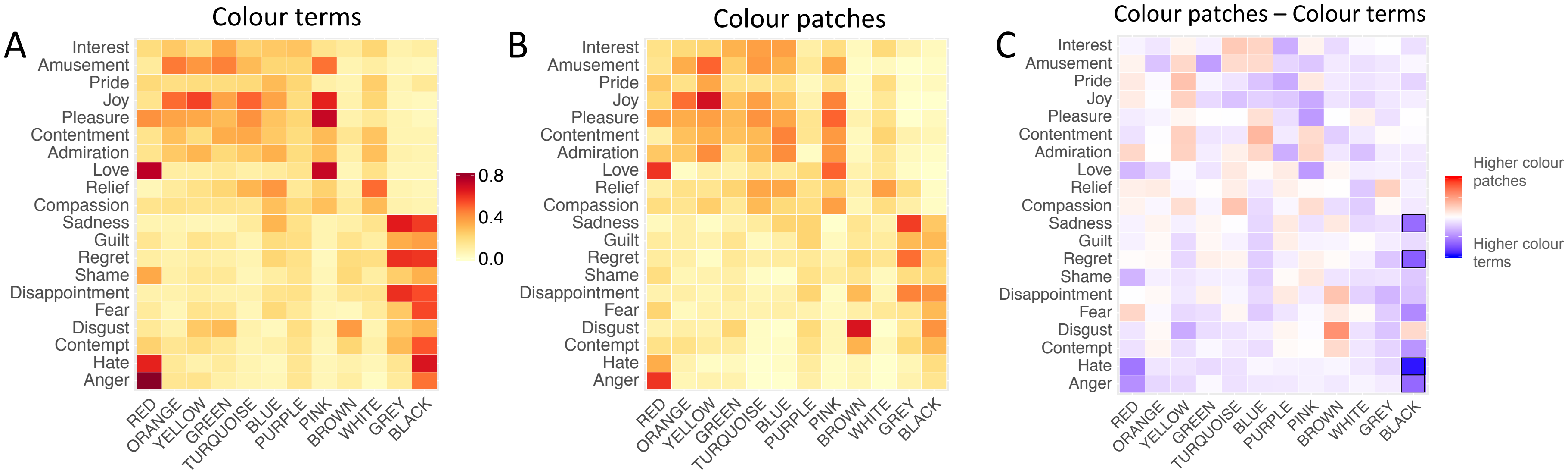


Figure 3.2. Heatmaps of colour-emotion associations.

Associations with (A) colour terms, (B) colour patches, and (C) the difference in colour-emotion associations between colour patches and colour terms. (A & B) Redder cells symbolise higher proportions of participants endorsing colour-emotion associations. (C) Redder cells symbolise higher proportions of participants endorsing colour-emotion associations with colour patches; bluer cells symbolise higher proportions of participants endorsing colour-emotion associations with colour terms; dark cell borders indicate statistically significant differences.

Table 3.3. The number of emotion concepts (broadness) associated with colour terms and colour patches together and separately.

All p-values are FDR corrected; *** $p_{FDR} < .001$.

	Colour (term and patch)			Colour term			Colour patch				
Colour	*M*	95% *CI*	Range	*M*	95% *CI*	Range	*M*	95% *CI*	Range	*t*-value	Cohen's *d*
Red	4.70	[3.98, 5.43]	0-20	5.00	[4.02, 5.98]	1-20	4.28	[3.18, 5.37]	0-17	0.98	0.17
Orange	3.45	[2.86, 4.03]	0-20	3.59	[2.72, 4.46]	0-20	3.24	[2.54, 3.94]	0-9	0.62	0.11
Yellow	3.96	[3.32, 4.61]	0-20	3.97	[3.09, 4.86]	0-20	3.94	[2.99, 4.90]	0-16	0.05	0.01
Green	3.64	[3.01, 4.27]	0-20	3.92	[2.99, 4.86]	0-20	3.24	[2.47, 4.01]	0-11	1.13	0.19
Turquoise	3.48	[2.87, 4.1]	0-20	3.47	[2.60, 4.35]	0-20	3.50	[2.67, 4.33]	0-11	-0.04	0.01
Blue	3.95	[3.33, 4.58]	0-20	4.17	[3.24, 5.10]	0-20	3.65	[2.89, 4.41]	1-11	0.86	0.15
Purple	3.26	[2.65, 3.87]	0-20	3.56	[2.64, 4.48]	0-20	2.81	[2.12, 3.51]	0-10	1.30	0.22
Pink	4.23	[3.6, 4.85]	0-20	4.42	[3.54, 5.30]	0-20	3.94	[3.06, 4.83]	1-12	0.77	0.13
Brown	2.53	[1.9, 3.16]	0-20	2.50	[1.58, 3.42]	0-20	2.57	[1.76, 3.39]	0-14	-0.12	0.02
White	3.01	[2.4, 3.61]	0-20	3.45	[2.52, 4.37]	0-20	2.37	[1.73, 3.01]	0-12	1.91	0.32
Grey	3.70	[3.1, 4.31]	0-20	4.13	[3.22, 5.03]	0-20	3.09	[2.39, 3.80]	0-13	1.80	0.31
Black	4.51	[3.87, 5.14]	0-20	5.56	[4.64, 6.49]	0-20	2.98	[2.34, 3.63]	0-10	4.59***	0.77
Overall	3.70	[3.52, 3.88]	0-20	3.98	[3.72, 4.24]	0-20	3.30	[3.07, 3.53]	0-17	1.04	0.19

Valence

Following the results of the mixed-design MANOVA with a mixed-design ANOVA on valence, there was the main effect of valence, $F(1, 130) = 70.82$, $p < .001$, $\eta_p^2 = .353$, indicated a positivity bias. Participants overall associated more positive ($M = 2.10$, 95% $CI = [1.80, 2.40]$) than negative ($M = 1.54$, 95% $CI = [1.26, 1.83]$) emotion concepts with colours. A significant interaction between valence and colour presentation mode, $F(1,130) = 5.40$, $p = .022$, $\eta_p^2 = .040$, indicated that this positivity bias was only present for patches ($p_{FDR} = .012$; terms: $p_{FDR} = .181$).

A significant interaction between valence and colour, $F(11, 1430) = 76.39$, $p < .001$, $\eta_p^2 = .370$, indicated that colours differed in valence. To break down this interaction, we used a series of post-hoc *t*-tests, FDR adjusted for multiple comparisons, to compare the number of positive and negative emotion concepts associated with each colour (so-called *valence bias*). *Pink, white, green, orange, blue, yellow,* and *turquoise* were all significantly biased towards positive associations (all $ps_{FDR} < .001$) while *black, grey,* and *brown* (all $ps_{FDR} < .001$) were significantly biased towards negative associations. *Red* ($p_{FDR} = .974$) and *purple* ($p_{FDR} = .765$) exhibited no valence bias, meaning that the same number of positive and negative emotion concepts was on average associated with these colours (Figure 3.3.A & B, Table S 19).

A significant three-way interaction between valence, colour, and colour presentation mode, $F(11, 1430) = 3.70$, $p < .001$, $\eta_p^2 = .028$, suggested that the valence bias varied by colour presentation mode. A series of FDR corrected *t*-tests revealed that more negative emotion concepts were associated with *black* when presented as a term ($M = 4.92$, 95% $CI = [4.26, 5.59]$) than as a patch ($M = 2.74$, 95% $CI = [2.10, 3.38]$, $p_{FDR} < .001$). No other comparisons were significant (all $ps_{FDR} \geq .085$, Figure 3.3).

Arousal

Following the results of the mixed-design MANOVA with a mixed-design ANOVA on arousal, there was here was no main effect of arousal, $F(1, 130) = 1.37$, $p = .245$, $\eta_p^2 = .010$: participants associated the same number of emotion concepts of high ($M = 1.85$, 95% $CI = [1.56, 2.14]$) and low arousal ($M = 1.80$, 95% $CI = [1.51, 2.08]$) with colours. A significant two-way interaction between arousal and colour presentation mode was observed, $F(1,130) = 9.79$, $p = .002$, $\eta_p^2 = .070$. However, no statistically significant differences were seen in post-hoc tests.

A significant two-way interaction between arousal and colour, $F(11,1430) = 57.69$, $p < .001$, $\eta_p^2 = .307$, showed that colours differed in how arousing they were (*arousal-bias*). FDR corrected post-hoc tests demonstrated that *red* ($p_{FDR} < .001$), *pink* ($p_{FDR} < .001$), *yellow* ($p_{FDR} < .001$), and *orange* ($p_{FDR} = .001$) were associated with a greater number of high compared to low arousal emotion concepts. *Grey* ($p_{FDR} < .001$), *brown* ($p_{FDR} < .001$), *white* ($p_{FDR} < .001$), *black* ($p_{FDR} < .001$), and *blue* ($p_{FDR} = .012$) yielded a greater number of low compared to high arousal emotion concepts. *Purple* ($p_{FDR} = .084$), *turquoise* ($p_{FDR} = .327$), and *green* ($p_{FDR} = .867$) did not differ in terms of arousal (see Figure 3.3.A & Table S 19. The three-way interaction between arousal, colour, and colour presentation mode was not significant, $F(11, 1430) = 1.63$, $p = .085$, $\eta_p^2 = .012$.

Power

Following the results of the mixed-design MANOVA with a mixed-design ANOVA on power, there was here was no main effect of power, $F(1, 130) = 2.16$, $p = .144$, $\eta_p^2 = .016$, indicating that participants associated the same number of strong ($M = 1.85$, 95% $CI = [1.57, 2.14]$) and weak ($M = 1.79$, 95% $CI = [1.50, 2.08]$) emotion concepts with colours. Despite a two-way interaction effect between power and colour presentation mode, $F(1,130) = 7.05$, $p = .009$, $\eta_p^2 = .051$, no statistically significant differences were seen in post-hoc tests.

A significant two-way interaction effect between power and colour, $F(11,1430) = 31.69$, $p < .001$, $\eta_p^2 = .196$, demonstrated that colours differed in power (*power-bias*). FDR corrected Post-hoc tests demonstrated that *yellow* ($p_{FDR} < .001$), *red* ($p_{FDR} < .001$), *orange* ($p_{FDR} < .001$), *green* ($p_{FDR} < .001$), and *turquoise* ($p_{FDR} = .027$) were associated with a greater number of strong emotion concepts than weak emotion concepts. *Grey* ($p_{FDR} < .001$), *white* ($p_{FDR} < .001$), and *blue* ($p_{FDR} = .002$) were associated with a greater number of weak compared to strong emotion concepts. *Purple* ($p_{FDR} = .341$), *black* ($p_{FDR} = .576$), *pink* ($p_{FDR} = .904$), and *brown* ($p_{FDR} = .905$) did not differ in terms of power (see Figure 3.3.B & Table S 19). The three-way interaction effect between power, colour, and colour presentation mode was not significant, $F(11, 1430) = 1.37$, $p = .181$, $\eta_p^2 = .010$.

3.4.3. Emotion Intensity

An independent samples *t*-test showed that emotion concepts of higher intensity were associated more with terms than with patches, $t(130) = 2.32$, $p = .022$, $d = 0.41$. Analyses for individual colours, after the FDR correction for multiple comparisons, indicated that this difference was only present for *black* (Table 3.4)

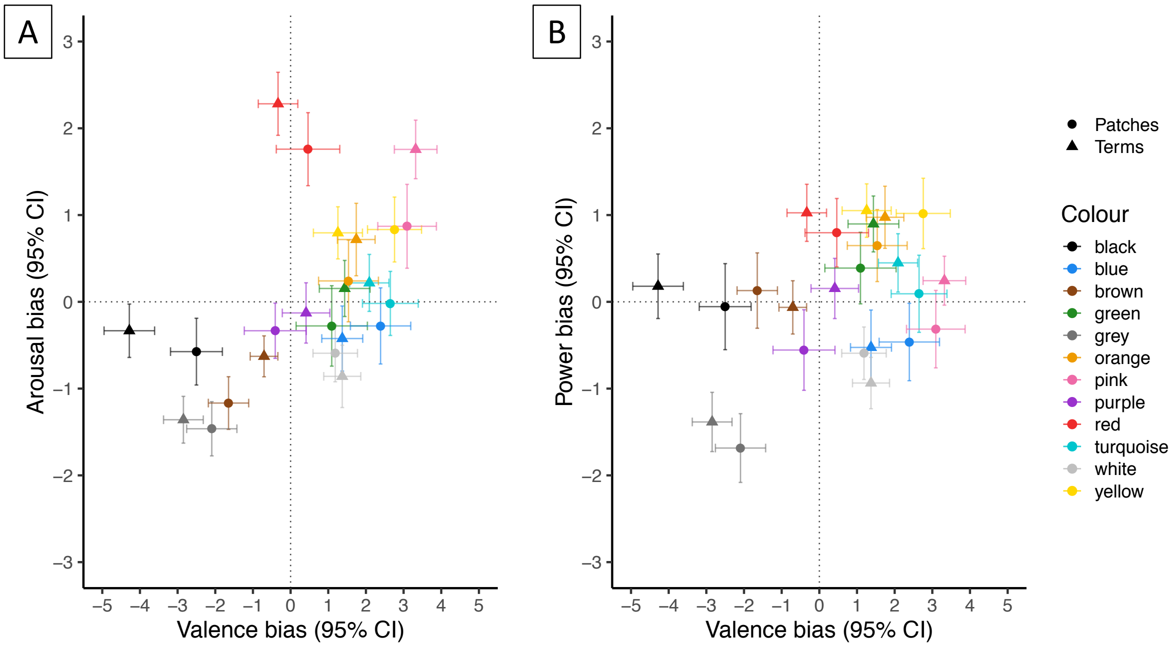


Figure 3.3. Valence, arousal, and dominance biases of each colour term (triangles) and colour patches (circles).

(A) Colours positioned on the valence x arousal space. Valence bias was calculated by subtracting the number of negative emotion concepts from the number of positive emotion concepts associated with each colour (positive - negative); higher values indicate a more positive evaluation. Arousal bias calculated by subtracting the number of low arousal emotion concepts from the number of high arousal emotion concepts associated with each colour (high arousal – low arousal); higher values indicate a more arousing evaluation. (B) Colours positioned on the valence x power space. Power bias calculated by subtracting weak emotion concepts from strong emotion concepts associated with each colour (strong – weak); higher values indicate a more empowering evaluation. (A & B) Error bars indicate 95% confidence intervals (CI) of the mean. Dotted lines indicate the separation between positive-negative, high arousal-low arousal, and strong-weak emotion concepts. Colours are for visualisation purposes only. See Table S 19 for the exact values.

Table 3.4. Descriptive values of the intensity of the associated emotion concepts with colour terms and colour patches together and separately.

Significant differences, after the FDR correction, in emotion intensity between colour presentation modes are flagged as * p_{FDR} < .050, ** p_{FDR} < .010.

	Colour (term and patch)			Colour term			Colour patch					
Colour	*M*	95% *CI*	Range	*M*	95% *CI*	Range	*M*	95% *CI*	Range	*N*	*t*-value	Cohen's *d*
Red	3.86	[3.70, 4.01]	1.9-5.0	3.99	[3.82,4.17]	1.9-5.0	3.65	[3.38,3.93]	1.0-5.0	130	2.16	0.39
Orange	3.32	[3.15, 3.49]	1.0-5.0	3.36	[3.16,3.57]	1.0-5.0	3.25	[2.95,3.56]	1.0-5.0	120	0.62	0.11
Yellow	3.55	[3.39, 3.70]	1.0-5.0	3.55	[3.34,3.76]	1.0-5.0	3.54	[3.30,3.79]	1.0-5.0	129	0.04	0.01
Green	3.24	[3.07, 3.41]	1.0-5.0	3.38	[3.20,3.56]	1.0-5.0	3.05	[2.72,3.38]	1.0-5.0	124	1.90	0.35
Turquoise	3.51	[3.32, 3.71]	1.0-5.0	3.66	[3.42,3.90]	1.0-5.0	3.31	[2.99,3.63]	1.0-5.0	118	1.80	0.34
Blue	3.44	[3.29, 3.59]	1.0-5.0	3.49	[3.28,3.70]	1.0-5.0	3.37	[3.15,3.60]	1.3-5.0	128	0.74	0.13
Purple	3.21	[3.02, 3.40]	1.0-5.0	3.32	[3.09,3.55]	1.0-5.0	3.07	[2.75,3.40]	1.0-5.0	118	1.26	0.23
Pink	3.56	[3.39, 3.74]	1.0-5.0	3.72	[3.50,3.95]	1.0-5.0	3.34	[3.06,3.62]	1.0-5.0	129	2.13	0.38
Brown	3.34	[3.14, 3.53]	2.0-5.0	3.33	[3.10,3.57]	2.0-5.0	3.34	[3.01,3.68]	1.0-5.0	108	-0.07	-0.01
White	3.56	[3.36, 3.76]	1.7-5.0	3.69	[3.46,3.92]	1.7-5.0	3.37	[3.01,3.73]	1.0-5.0	116	1.56	0.30
Grey	3.55	[3.37, 3.72]	1.8-5.0	3.61	[3.38,3.84]	1.8-5.0	3.45	[3.17,3.74]	1.0-5.0	128	0.85	0.15
Black	3.62	[3.45, 3.79]	1.8-5.0	3.86	[3.67,4.04]	1.8-5.0	3.26	[2.95,3.57]	1.0-5.0	127	3.55**	0.64
Overall	3.49	[3.37, 3.61]	1.8-5.0	3.61	[3.46,3.75]	1.8-5.0	3.33	[3.12,3.53]	1.7-4.8	132	2.32*	0.41

3.5. Discussion

Research on colour-emotion associations has used colour patches or colour terms. In the former case, the perceptual attributes of colour are considered decisive. In the latter, perceptual attributes are little controlled and linguistic features are considered decisive. In the current study, we tested whether colour-emotion associations were comparable when using colour terms and colour patches (similar to Wang et al., 2014). Our French-speaking participants associated a large number of emotion concepts (Scherer, 2005; Scherer et al., 2013) with a representative number of either colour terms or patches, and rated the intensity of the associated emotion concepts. In analyses, we accounted for colour associations with i) specific emotions, ii) emotion dimensions (valence, arousal, and power; Fontaine et al., 2007), as well as iii) emotion intensity.

Cluster analysis indicated that colour associations with specific emotions differed in terms of frequency. Some associations were frequent (e.g., *red-anger, red-love, yellow-joy*), other associations occurred occasionally (e.g., *blue-sadness*), and still other associations were rare (e.g., *blue-love*). Some colours were associated with a single specific emotion (*brown-disgust*, *white-relief*), while others with several specific emotions (*red-love, red-anger*; *yellow-joy*, *yellow-amusement*). Further emotion associations were better described in terms of emotion dimensions. For instance, *black* was associated with mainly *negative* emotions, *grey* with *negative* and *weak* emotions, *blue* with *positive* emotions, and *green* with *positive* and *powerful* emotions. Important to our study, colour associations with specific emotions were very similar (similarity coefficient of .82) when contrasting the associations between colour terms and patches. Similarities ranged from .79 (*blue*) to .96 (*grey*), with the exception of low similarity for *purple* (-.23). The degree of dissimilarity is likely due to additional perceptual or linguistic factors, or perhaps noise in the data. In the current study, we observed some systematic dissimilarities between colour terms and colour patches. Participants, overall and particularly for *black*, i) were more likely to select an emotion concept for terms than for patches, and ii) selected emotion concepts of higher intensity for terms than for patches. Participants also associated more negative emotions with *black* when the colour was presented as a term than as a patch.

Our study showed a high degree of similarity in colour associations with specific emotions and emotion dimensions between colour terms and colour patches, at least in a French-speaking population. This similarity might indicate that emotions are associated with an abstract representation of colour (i.e., a colour concept; Abbott et al., 2016). This abstract representation can be accessed via colour perceptions, at least when they are close to focal colours, or basic colour terms. Potentially, similar shades of colour named by the same colour term might be associated with more comparable emotions than similar shades of colour named by different colour terms. For instance, when the colour name *red* denoted both a typical red (i.e., potentially focal) and a dark shade of red, the same emotion associations emerged (i.e., *anger* and *love;* Fugate & Franco, 2019). In contrast, in our study, focal red (i.e., named *red*) was associated with positive and negative emotions (i.e., *love*, *anger*, and *hate*), while light red (i.e., named *pink*) was exclusively associated with positive emotions (i.e., *love, joy,* and *pleasure*; also see, Fugate & Franco, 2019; Gil & Le Bigot, 2014; Jonauskaite, Dael, et al., 2019; Kaya & Epps, 2004; Sutton & Altarriba, 2016). Despite these observations, lightness and saturation might play a more important role than hue when shades of colour are drastically different (e.g., Dael et al., 2015; Palmer et al., 2013; Specker et al., 2018; Valdez & Mehrabian, 1994).

High similarity in emotion associations with colour terms and colour patches held for almost all colours. For instance, we replicated the widely observed association between lightness and positivity (Allan, 2009; Lakens et al., 2013b; Meier et al., 2007; Specker et al., 2018; Valdez & Mehrabian, 1994). Whether lightness was perceived or only imagined, *white* was associated with exclusively positive emotions and *black* and *grey* with exclusively negative emotions. Other colours were associated with both known and new emotions. For instance, in addition to associating *yellow* with *joy* (e.g., Fugate & Franco, 2019; Sutton & Altarriba, 2016b) and *brown* and *disgust* (e.g., Fugate & Franco, 2019), our participants also associated *yellow* with *amusement*, *orange* with *joy* and *amusement*, and *turquoise* with *joy* and *pleasure*.

The only colour that exhibited different specific emotion associations when presented as a term and as a patch was *purple.* While the pattern of emotion associations with *purple* was uncorrelated between terms and patches, *purple* did not carry widely shared associations with emotion concepts. No emotion concept was chosen for *purple* by more than 20% of participants. Other empirical studies have already suggested that *purple* carries idiosyncratic emotion connotations (Fugate & Franco, 2019; Hemphill, 1996; Hupka et al., 1997; Sutton & Altarriba, 2016b). Hence, *purple* might be the most affectively neutral or the most affectively ambiguous colour.

Another colour that was somewhat different between terms and patches was *black*. However, *black* did not differ in terms of *which* emotions were associated, only in terms of *how likely* the associations were. Whether *black* was presented as a term or a patch, it was associated with almost all of the given negative emotions (i.e., *sadness, guilt, regret, disappointment, fear, disgust, contempt, hate,* and *anger*; see also, Adams & Osgood, 1973; Burkitt & Sheppard, 2014; Fugate & Franco, 2019; Hanada, 2018; Specker et al., 2018; Valdez & Mehrabian, 1994). When *black* was a term, however, the negative associations were stronger and more intense, especially with *hate, anger, regret*, and *sadness*. Potentially, terms evoke colour percepts that differ from patches. Uusküla and Eessalu (2018) showed that the supposedly *black* glossy Munsell colour chip was named as *black* only by a minority of their participants in a colour naming study. If our *black* colour patch was not *black* "enough", participants might have for that reason associated the patch with fewer negative emotions. Another possibility is the difference between *black* in the linguistic and perceptual contexts. *Black* might evoke more negative associations linguistically (e.g., *black magic*, *blackmail*, etc., Allan, 2009) rather than perceptually, the latter triggering notions of sophistication and elegance (Labrecque & Milne, 2012). Hence, while being associated with similar negative emotions perceptually and linguistically, *black* was even more negative in the linguistic context.

Based on different theoretical frameworks, we expected that certain colour-emotion associations might be more prevalent in frequency and / or intensity when conveyed linguistically (i.e., *blue* and *sadness*, *yellow* and *negative* emotions) while others might be more prevalent in frequency and / or intensity when conveyed perceptually (i.e., *yellow* and *joy*, *blue* and *positive* emotions). Our data demonstrated that *yellow* was associated with *joy* (also see, Jonauskaite, Althaus, et al., 2019; Kaya & Epps, 2004; Sutton & Altarriba, 2016), which is likely explained by its link to sunshine (Jonauskaite, Abdel-Khalek, et al., 2019). *Yellow* was not associated with any *negative* emotion, as some colour expressions would have predicted (e.g., *yellow-bellied* or *rire jaune [yellow laughter]*). Our data also showed that *blue* was associated with *positive* emotions (also see, Adams & Osgood, 1973; Kaya & Epps, 2004; Manav, 2007;

Valdez & Mehrabian, 1994; Wexner, 1954), potentially related to experiences of a clear sky or clean water (Palmer & Schloss, 2010). *Blue* was not in general associated with any *negative* emotion. The only negative association with *blue* was *sadness*, endorsed by 27% of our participants (see also, Barchard, Grob, & Roe, 2017; Palmer et al., 2013; Sutton & Altarriba, 2016). This association can be related to colour expressions like *feeling blue* in English and *avoirs des bleus à l'âme* (the soul being bruised, meaning feeling sad and melancholic) in French. Hence, these examples suggest that – relatively speaking – conceptual colour-emotion associations might have been more strongly reinforced by the perceptual rather than the linguistic systems. A more systematic investigation with a greater number of colours and emotions and a greater number of colour metaphors would be useful to examine this conjecture further.

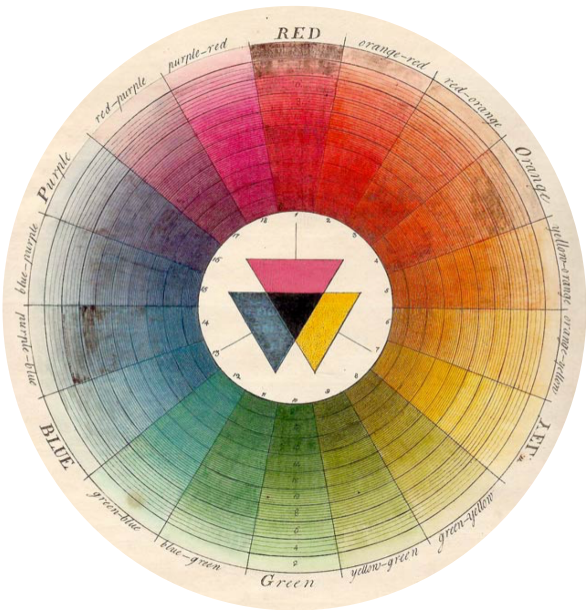
High emotion similarity between colour terms and colour patches cannot provide equivocal support to the theories favouring the role of language (e.g., conceptual metaphor theory; Lakoff & Johnson, 1999) or perception (e.g., Ecological Valence Theory; Palmer & Schloss, 2010). Of course, these theories have not focused on colour-emotion associations but instead propose generic association mechanisms. More specific to colour, Wang and colleagues (2014) proposed a distinction between “natural” and “social” colour-emotion associations. “Natural” associations are believed to be reinforced by perceptual pairings and “social” associations through linguistic and cultural pairings. They suggested that the association between *red* and *negative* emotions is “natural” and apparent when *red* is a patch, while an association between *red* and *positive* emotions is “social” and apparent when *red* is a term. We did not replicate the same distinction in the Swiss French-speaking population neither for *red* nor for any other colour. The valence of all 12 studied colours did not differ between terms and patches. It is unclear to what extent cultural or methodological differences could account for the discrepancy. For instance, in a related study linking 12 colour terms with 20 emotion concepts (Jonauskaite, Wicker, et al., 2019), Chinese participants chose a large number of positive emotions (especially, *love* and *joy*) for the term *red* but also associated *red* with *anger*. Hence, colour-emotion associations might be reinforced by perceptual, linguistic, and cultural systems and the weight of these factors might vary by culture.

Our results might inform theories of embodied cognition (e.g., Barsalou, 1999), providing evidence for an overlapping representation of linguistic and perceptual stimuli. For instance, the classic Stroop effect (Stroop, 1935) demonstrates how naming the ink of letters is hampered when the letters spell an inconsistent colour term. Similarly, auditory presentation of task-unrelated colour terms has been shown to interfere with discrimination performance for colour patches (Richter & Zwaan, 2009). Linguistic reference to *red,* by including the word *red* in the description of a person, increased their perceived attractiveness (Pazda & Elliot, 2017). Similarly, linguistic reference to *red*, when this word appeared on the exam sheet, hampered students' intellectual performance (Lichtenfeld et al., 2009). Equivalent effects on attractiveness and intellectual performance have been reported for perceptual experiences of *red* (Lehmann et al., 2018; M. A. Maier et al., 2008; Mehta & Zhu, 2009). A recent psychophysiological study showed that the words *darkness* and *brightness* triggered comparable pupillary responses to perceptual stimuli (Mathôt et al., 2017). Imaging studies have also demonstrated shared neural networks of colour perception and colour knowledge in the left fusiform gyrus (W. K. Simmons et al., 2007; Slotnick, 2009) and the left lingual gyrus (Hsu et al., 2012). On the other hand, the existence of distinct neurological conditions such as colour anomia (i.e., inability to name visually presented colours; Davidoff & Ostergaard, 1984), colour agnosia (i.e., inability to recognise colours; Davidoff, 1996) and cerebral achromatopsia (i.e., complete colour blindness after cortical damage; Zeki, 1990) provide evidence for (at least partly) separated neural networks. Hence, it appears that colour perception and colour semantics engage to some degree overlapping neural networks.

In conclusion, our results demonstrate that conceptual associations between emotions and colours were very similar when a colour was presented perceptually (i.e., patch of a focal colour) and linguistically (i.e., a basic colour term). Hence, studies associating emotions with colour terms or patches can be compared and their results integrated (with some caution taken for *purple* and *black*). Future studies can choose to study colour terms or colour patches based on their experimental design and not under the assumption that one method would give more accurate results than the other. Our results would indicate that emotion concepts are associated with a colour concept – an abstract representation of colour – rather than specific perceptual or linguistic properties of colour. This suggestion is true at least when perceived colours relate to focal colours. Future studies may investigate emotion associations with colour patches that are difficult to name (e.g., that border between two neighbouring colour terms; Parraga & Akbarinia, 2016) and with colour patches that vary in lightness and saturation but are named by the same basic term. Our results could also be replicated in a within-subject design to ensure that similarity between colour terms and patches holds within groups. Note that our study cannot determine whether language or perception drives colour-emotion relationships in the first place: we do not know whether colour patches were named or colour terms imagined, or both. To disentangle the origins of colour-emotion associations, it would be necessary to move towards less typical populations. For instance, studies in populations that possess different numbers of colour categories would be informative (see Maier & Abdel Rahman, 2018). Here, we demonstrated that, once acquired, conceptual colour-emotion associations depend little on how colour is presented.

Chapter 4.

The Sun Is No Fun Without Rain: Physical Environments Affect How We Feel About Yellow Across 55 Countries [19]



[19] **Jonauskaite, D.,** Abdel-Khalek, A. M., Abu-Akel, A., Al-Rasheed, A. S., Antonietti, J.-P., Ásgeirsson, Á. G., Atitsogbe, K. A., Barma, M., Barratt, D., Bogushevskaya, V., Bouayed Meziane, M. K., Chamseddine, A., Charernboom, T., Chkonia, E., Ciobanu, T., Corona, V., Creed, A., Dael, N., Daouk, H., … Mohr, C. (2019). The sun is no fun without rain: Physical environments affect how we feel about yellow across 55 countries. *Journal of Environmental Psychology*, *66*, 101350. https://doi.org/10.1016/j.jenvp.2019.101350

4.1. Abstract

Across cultures, people associate colours with emotions. Here, we test the hypothesis that one driver of this cross-modal correspondence is the physical environment we live in. We focus on a prime example – the association of yellow with joy, – which conceivably arises because yellow is reminiscent of life-sustaining sunshine and pleasant weather. If so, this association should be especially strong in countries where sunny weather is a rare occurrence. We analysed yellow-joy associations of 6,625 participants from 55 countries to investigate how yellow-joy associations varied geographically, climatologically, and seasonally. We assessed the distance to the equator, sunshine, precipitation, and daytime hours. Consistent with our hypotheses, participants who live further away from the equator and in rainier countries are more likely to associate yellow with joy. We did not find associations with seasonal variations. Our findings support a role for the physical environment in shaping the affective meaning of colour.

4.2. Introduction

Across cultures, people associate colours with emotions (Adams & Osgood, 1973). These associations may be attributed to linguistic and cultural factors. If so, one's built and natural environments need to be considered too, because one's environment interacts with one's psychological functioning. In this context, colour is an obvious descriptor of one's physical environment, and is thought to directly influence our psychological functioning (Jalil et al., 2012). For instance, pink rooms were proposed to reduce aggressiveness in prisoners (Schauss, 1979; but see Genschow, Noll, Wänke, & Gersbach, 2015). Others suggested that green reduces stress in hospital environments (Dijkstra et al., 2008). We focus on natural variations in our physical environments to test whether these variations can predict how people associate colours with emotions. We chose yellow, because yellow is commonly, although not exclusively, associated with joy (Burkitt & Sheppard, 2014; Dael et al., 2016; Jonauskaite, Althaus, et al., 2019; Kaya & Epps, 2004; Lindborg & Friberg, 2015; Sutton & Altarriba, 2016b). This affective association might originate from saturated yellow co-occurring with positive climatological experiences like sunshine (Griber et al., 2018; Palmer & Schloss, 2010) and warmth (Ou et al., 2004).

Sunshine, and pleasant weather more generally, have been related to better mood in French and American participants (Guéguen, 2013; Keller et al., 2005). However, since research is primarily focused on individuals from Western countries (Henrich et al., 2010), this positive evaluation of sunshine might not hold globally. Rather, the association of joy with sunshine might be further modulated by warmth and rainfall. Sunshine, warmth, and sufficient rain are necessities for life and growth whereas sunshine alone might lead to drought and death. Thus, people in the Sahara Desert, where yellow is the colour of sand and the burning sun, might rate yellow as less joyful than Norwegians. Joyfulness of yellow might be further reduced when daylight is plentiful (i.e., midsummer) compared to when daylight is scarce (i.e., midwinter). Hence, geographic, climatological, and seasonal factors may modulate one's affective associations with yellow.

We tested these putative associations with data gathered from our ongoing International Colour-Emotion Survey (Mohr et al., 2018). We tested whether sunshine, distance to the equator, precipitation, and number of daytime hours, when the survey was completed, predict the strength of the association of yellow with joy in over 6,500 participants living in 55 different countries. We hypothesised that participants living in less sunny countries, further away from the equator and/or with heavier rainfall would endorse the yellow-joy association to a greater extent than people living in sunnier countries, located closer to the equator and/or with lighter rainfall. Furthermore, we expected stronger associations when daylight was scarce compared to when daylight was plentiful.

4.3. Method

4.3.1. Participants

We extracted responses on yellow-joy associations from a larger data set (see the ongoing International Colour-Emotion Survey (Mohr et al., 2018) (http://www2.unil.ch/onlinepsylab/colour/main.php). This survey aims to evaluate colour-emotion associations in as many countries as possible. To include a wide range of geographic locations, we included countries for which we had at least 20 useable participants (see Simmons, Nelson, & Simonsohn, 2011 for choice of minimum sample size; see "Data preparation" for inclusion criteria). This procedure left us with 6625 participants (1669 males) living in one of 55 countries (Table 4.1).

Table 4.1. The number of participants (*n*) from each of the 55 countries included in the current study.

See Table S 20 for further demographic information.

Country (*n*)	**Country (*n*)**	**Country (*n*)**	**Country (*n*)**	**Country (*n*)**
Algeria (57)	Cyprus (324)	Iran (123)	Nigeria (127)	Spain (201)
Argentina (65)	Denmark (29)	Israel (82)	Norway (275)	Sweden (265)
Australia (54)	Egypt (159)	Italy (115)	Peru (22)	Switzerland (346)
Austria (53)	Estonia (131)	Japan (26)	Poland (164)	Taiwan (60)
Azerbaijan (433)	Finland (138)	Kenya (25)	Portugal (31)	Thailand (30)
Bangladesh (21)	France (93)	Latvia (28)	Romania (24)	Togo (34)
Belgium (103)	Gabon (30)	Lebanon (74)	Russia (115)	Turkey (91)
Bulgaria (32)	Georgia (133)	Lithuania (126)	Saudi Arabia (141)	United Kingdom (206)
China (181)	Germany (250)	Mexico (120)	Serbia (109)	Ukraine (74)
Colombia (102)	Greece (499)	Netherlands (119)	South Africa (25)	USA (151)
Croatia (70)	Iceland (71)	New Zealand (223)	South Korea (24)	Zimbabwe (20)

The mean age (always in years) of participants was 33.87 (*95% CI* = [33.87, 34.21], range: 16-87). Table S 20 displays information regarding the language of the survey, age, and gender composition, separately for each country. The included participants were not colour-blind according to self-report. The survey was conducted in accordance with the principles expressed in the Declaration of Helsinki. No formal ethics approval was received in Switzerland since the law of the Canton of Vaud, Switzerland, does not require it for behavioural studies.

4.3.2. Material and Procedure

Geneva Emotion Wheel

Geneva Emotion Wheel (GEW; version 3.0; Scherer et al., 2013) is a self-report measure to assess the subjective feeling component of emotions. GEW presents 20 discrete emotions *(interest, amusement, pride, joy, pleasure, contentment, admiration, love, relief, compassion, sadness, guilt, regret, shame, disappointment, fear, disgust, contempt, hate,* and *anger*) organised in a circular fashion, with similar emotions being placed close to each other (see Table S 21 for *joy* in all the languages). For each emotion, five radially aligned circles and a square are used to rate the intensity of the emotion. Selecting the square located closest to the centre of the wheel means that the emotion intensity is zero (i.e., the given emotion is not perceived as associated with the given colour term). Selecting one of the five circles of increasing size means that the emotion is perceived as being associated with the colour term; the larger the selected circle, the more intense the emotion. Thus, a six-point ordinal rating scale (0-5) was used, with the lowest scale category representing the absence of a colour-emotion association.

International Colour-Emotion Association Survey

The co-authors and collaborators were responsible for data collection in their respective countries. Participants were invited to complete the survey online, in their native language. Here, they were included regardless of which language they chose (see "Data preparation"). We facilitated local data collection by using links that directly opened in the target language (see Table S 22). At the time of data extraction (February 2019), our survey was available in 40 different languages. Native speakers, many of whom co-author this article, had translated the survey and the GEW emotion terms into their respective languages (see complete list of translators in the Acknowledgments section). Bilingual speakers back-translated the emotion terms to ensure compatibility between languages.

The survey started by stating its main goal, providing ethical information (i.e., participation is anonymous and strictly confidential, responses are to be used for research purposes and its dissemination, participants can stop the survey at any time with no consequences) and collecting informed consent – participants knowingly consented by clicking on the "Let's go" button. The next two pages explained the task and how to use the GEW. To ensure that participants had understood the task, they performed a practice trial for "beige", a colour term not used in the actual survey. Participants had to correct the choices made by Peter, a fictional character. Once corrected, participants could continue to the experiment, in which they associated emotions with 12 colour terms (*red, orange, yellow, green, blue, turquoise, purple, pink, brown, black, grey,* and *white;* see Table S 21 for *yellow* in all the languages) and evaluated emotion intensities. The colour terms were presented above the GEW display, and colour order was randomised. Participants could select one, several, or none of the GEW emotions. Participants rated the emotion intensities by clicking on the corresponding circle. Colour terms were chosen instead of colour patches because accurate colour presentation cannot be ensured when showing colour patches online.

After rating the 12 colour terms, participants reported age, gender, colour blindness ("*Do you have any trouble seeing certain colours?*"), colour importance in their life, country of origin and country of residence ("*What is your country of residence? The most recent country you have been living in for at least 2 years*"), native language, and fluency of the language they used to complete the colour-emotion survey. A "*do not want to answer*" option was available for all questions. On the final page, participants were thanked and graphically presented with the results from a previous, related study. Participants were further able to contact us via an e-mail address. On average, our participants took 13.9 minutes to complete the survey (http://www2.unil.ch/onlinepsylab/colour/main.php).

Geographic, Climatological, and Seasonal Factors

We extracted three measures for each country of residence. First, s*unshine* – percentage of sunny hours per year, calculated by dividing the number of sunshine hours per year (https://en.wikipedia.org/wiki/List_of_cities_by_sunshine_duration) by the total number of daytime hours in a year (i.e., 12 h x 365 days = 4,380h). This number was then multiplied by 100. Second, *absolute latitude* – distance to the equator of each country (central point) expressed in absolute latitude degrees (https://developers.google.com/public-data/docs/canonical/countries_csv; we ignored the +/- sign). Higher absolute latitude degrees indicate that a country is located further away from the equator and is colder. Third, *precipitation* – annual precipitation levels measured as millimetres (mm) of rainfall per year (https://data.worldbank.org/indicator/AG.LND.PRCP.MM). See Table S 23 for data of each country. This precipitation variable was chosen to complement the sunshine variable for two reasons. Firstly, few sunshine hours indicate more clouded hours, which may or may not be accompanied by rain/snow. Second, precipitation provides information about the amount of rainfall/snowfall that reached the ground. However, one could imagine situations when weak rainfall lasts all day (i.e., low sunshine and low rainfall) or when heavy rainfall lasts for a short period of time (i.e., high sunshine and high rainfall). Thus, we considered sunshine, latitude, and precipitation as complementary predictor variables.

The sunshine, precipitation, and latitude measures were calculated per country and represent values that were based on averages extracted from assessments over several years (sunshine and precipitation). To account for individual, seasonal factors, we further calculated for each participant the number of *daytime hours* on the day the participant completed the survey. We defined daytime hours as the number of hours between the country-specific sunrise and sunset time. To make the calculation, we took into account the day of the year when the survey was completed and the latitude of participants' country of residence (see *Supplementary Material* for derivation and R code). A greater number of daytime hours occur during local summer and fewer daytime hours during local winter, especially in countries further away from the equator.

4.3.3. *Data Preparation*

Our exclusion criteria are the same used before (e.g., Jonauskaite, Dael, et al., 2019). We excluded participants who were too quick (i.e., took < 3 min to complete the main task) or too slow (took > 90 min to complete the main task). We also excluded participants who seemed not to engage with the task (i.e., spent < 20 seconds rating the first four colour terms). We did not exclude participants even if they did not complete the survey in their indicated native language, as long as their fluency of the survey language was sufficiently high (i.e., scored at least 5 on 1-8 scale). This criterion allowed the inclusion of immigrants and accounted for native languages in formerly colonised countries (e.g., Swahili speakers in Kenya who completed the survey in English). Finally, we excluded participants who had missing data on the yellow-joy association (i.e., provided no association, not even 0). The dataset contained the occasional missing data, because of technical problems when recording answers. See Table S 24 for the count of excluded participants at each step of the data cleaning procedure. Cleaned data are available here: https://forsbase.unil.ch/project/study-public-overview/15126/1672/

4.3.4. *Design and Statistical Analyses*

All data were analysed and graphs were created using R (v. 3.4.0) statistical programming language. We started by assessing the correlations between the geographical and climatological predictors. None of the predictors seemed redundant as shown by average correlation coefficients (all $|r| \leq .478$; Table S 25). Also, the variance inflation factor in the regression model was acceptable (VIF ≤ 2.35) indicating no issue of multicollinearity. Thus, we kept all predictor variables to compute our models. These models were run on the *intensity* of yellow-joy associations (scores of 0 to 5). For descriptive purposes, we also calculated the percentage of participants associating yellow with joy (*likelihood of association*) by dividing the number of participants who associated *joy* of any intensity (1-5) with *yellow* by the total number of participants in each country and multiplying this outcome by 100%.

For the main analysis, we computed the hierarchical cumulative link mixed models with a random effect via Laplace approximation (*clmm* function in R package *ordinal;* Christensen, 2018). This analysis is a hierarchical nested regression model for ordinal data. We estimated the amount of explained variance in the intensity of yellow-joy associations (range of scores from 0 to 5) by the geographical, climatological, and seasonal predictors. We chose a hierarchical regression model to assess the explained variance of each predictor variable in order: from sunshine, which seemed an obvious variable according to our hypotheses, to absolute latitude, precipitation, and, finally, daytime hours. We chose a cumulative link model to account for the ordinal nature of the dependent variable (discrete responses measured on a six-point ordinal scale from 0 to 5). We chose a mixed-effects model because geographical and climatological variables varied by country and not by individual participants; therefore, within country variance was of little interest here. Fixed effects were sunshine, absolute latitude, precipitation, and daytime hours. Country was a random effect. To prevent numerical issues in model estimations, we rescaled the precipitation variable by dividing all precipitation values by 1000.

In block 0, we entered no predictors. In the next block (block 1; see Table 4.2), we added sunshine. In the following blocks, we assessed, in this order, sunshine and latitude (block 2), then sunshine, latitude, and precipitation (block 3), and finally sunshine, latitude, precipitation, and daytime hours (block 4). We used likelihood ratio tests (R function *anova*), because these tests sequentially compared every block to establish whether each new predictor changed the amount of explained variance in the intensity of yellow-joy associations. We determined the best model based on the significant change in the overall goodness-of-fit of the model as well as based on the Akaike Information Criterion (AIC), where lower values indicate a better fit.

4.4. Results

The likelihood of yellow-joy associations varied across our 55 countries, ranging from just 5.7% in Egypt to 87.7% in Finland (Figure 4.1; Table S 26). The global average of the likelihood of yellow-joy associations was 48.26% (*95% CI* = [46.86, 49.26]). We present associations between yellow and other positive and negative emotions in Table S 27 and Table S 28 respectively.

The likelihood ratio test showed that the model with sunshine (block 1) was significant; *LR*(4) = 17.98, $p < .001$, *AIC* = 17,116, ${}_{pseudo}R^2$ = .139 (Cox & Snell), .149 (Nagelkerke). The model with sunshine and absolute latitude (block 2) was superior to the model with sunshine alone (block 1) in explaining the intensity of yellow-joy associations; *LR*(5) = 5.43, $p = .020$, *AIC* = 17,112, ${}_{pseudo}R^2$ = .140 (Cox & Snell), .150 (Nagelkerke). The model accounting for sunshine, absolute latitude, and precipitation (block 3) was superior again to the model accounting for sunshine and absolute latitude alone (block 2); *LR*(6) = 5.78, $p = 0.016$, *AIC* = 17,109, ${}_{pseudo}R^2$ = .141 (Cox & Snell), .151 (Nagelkerke). Finally, the goodness-of-fit of the model including sunshine, absolute latitude, precipitation, and daytime hours (block 4) was not superior to the model including just sunshine, absolute latitude, and precipitation (block 3); *LR*(7) = 0.53, $p = 0.46$, *AIC* = 17,110, ${}_{pseudo}R^2$ = .141 (Cox & Snell), .151 (Nagelkerke). Therefore, this hierarchical regression approach showed that the variation in the intensity of yellow-joy associations can be best explained when accounting for sunshine, absolute latitude, and precipitation (block 3). Parameter estimates of individual predictors of block 3 showed that higher absolute latitude and higher precipitation significantly predicted a higher intensity of yellow-joy associations, while sunshine was not a significant predictor when these other variables were included (Table 4.2).

Table 4.2. Likelihood ratio tests to predict yellow-joy relationship.

The table displays unstandardized coefficients (*B*), standard errors of unstandardized coefficients (*SE*), standardized coefficients (β), odds ratios with 95% confidence intervals (CI), and *z*-values associated with each predictor in each block of the hierarchical regression predicting the intensity of yellow-joy associations. The best model is marked in bold.

	B (SE)	β	Odds ratio (95% CI)	*z*-value
Block 1				
sunshine	-0.031 (0.007)	-0.435	0.969 [0.956, 0.982]	-4.67***
Block 2				
sunshine	-0.024 (0.007)	-0.335	0.976 [0.962, 0.990]	-3.38***
absolute latitude	0.014 (0.006)	0.198	1.015 [1.003, 1.027]	2.37*
Block 3				
sunshine	-0.009 (0.009)	-0.119	0.991 [0.973, 1.009]	-0.93
absolute latitude	0.025 (0.007)	0.346	1.026 [1.011, 1.040]	3.51***
precipitation (scaled)	0.485 (0.194)	0.263	1.625 [1.244, 2.005]	2.50*
Block 4				
sunshine	-0.008 (0.009)	-0.116	0.992 [0.974, 1.010]	-0.90
absolute latitude	0.025 (0.007)	0.347	1.026 [1.012, 1.040]	3.51***
precipitation (scaled)	0.492 (0.195)	0.266	1.636 [1.254, 2.018]	2.52*
daytime hours	-0.008 (0.012)	-0.023	0.991 [0.968, 1.015]	-0.73

*$p < .050$, ***$p < .001$

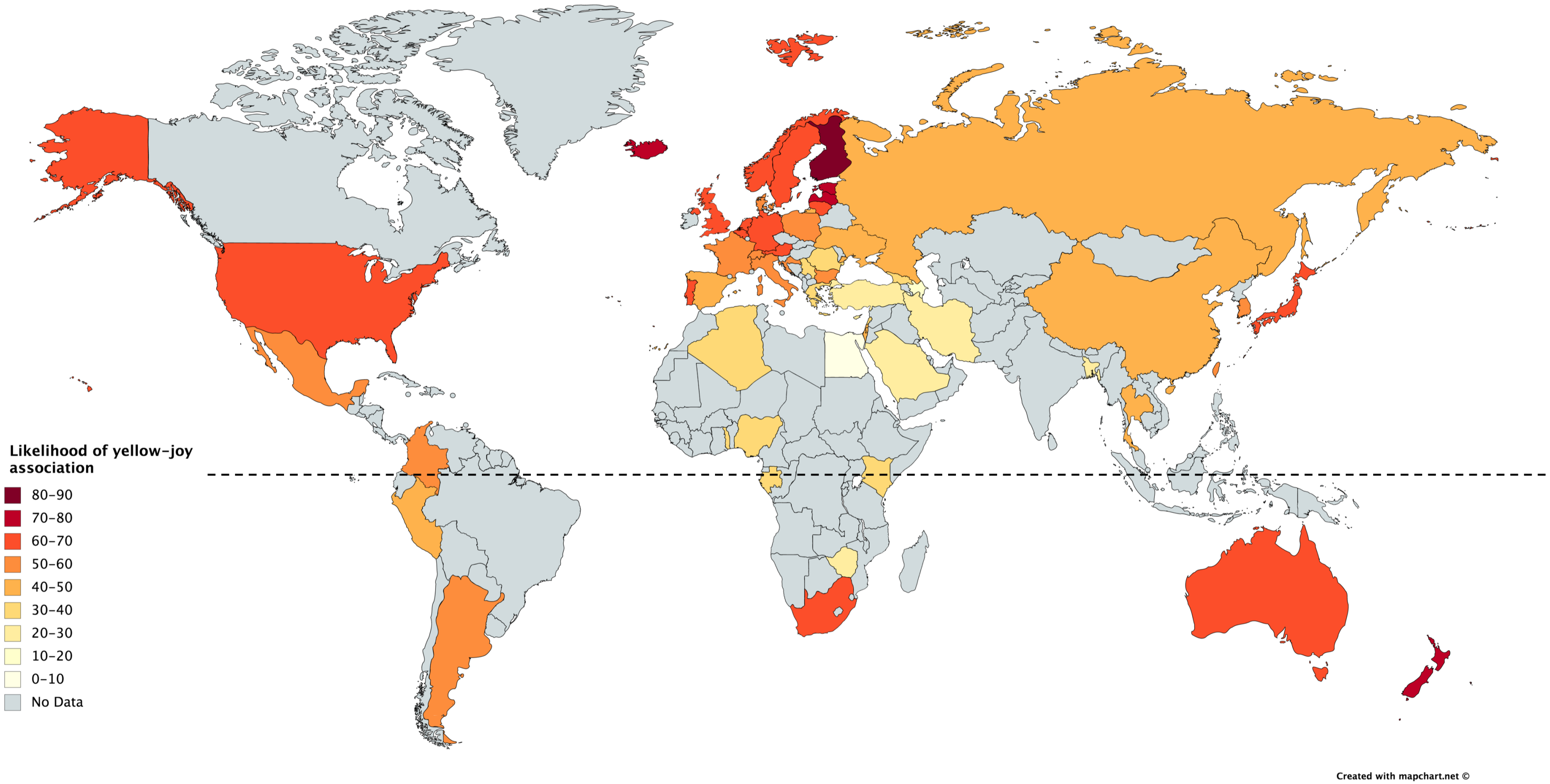


Figure 4.1. Likelihood of associating yellow with joy in 55 countries.

This map of the world (data not collected in grey countries) shows the likelihood of associating yellow with joy (0%-90%), where darker and redder areas indicate a higher likelihood (i.e., proportion of participants endorsing the yellow-joy association). The dotted line shows the equator. Map created with the free software on https://mapchart.net/.

4.5. Discussion

We tested whether one's physical environment might influence how one attaches emotional meaning to colours. More precisely, we tested the hypothesis that geographic, climatological, and seasonal factors might impact yellow-joy associations in 55 countries. We replicated previous findings showing that yellow is predominantly associated with joy (e.g., Jonauskaite, Althaus, et al., 2019; Kaya & Epps, 2004; Lindborg & Friberg, 2015). About 48.3% of our participants endorsed an association between yellow and joy. We observed no comparably compelling associations with any other emotions. Yet, the percentage of participants endorsing this association varied widely, from just 5.8% in Egypt to 87.7% in Finland (see also Barchard, Grob, & Roe, 2017). Overall, participants rated yellow as more joyful if they lived in rainier countries located further away from the equator. This conclusion is based on an analysis in which we used the centre of each country as the point of reference. Although this provides a good estimate of a country's latitude, it will be less reflective of the participant's latitude in large countries.

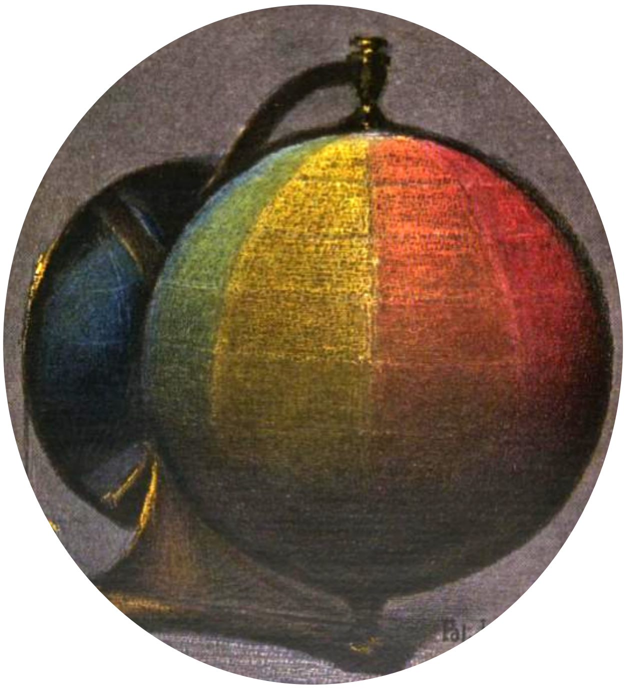
We initially hypothesized that scarcity of sunshine is a key contributor to yellow-joy associations (Guéguen, 2013; Palmer & Schloss, 2010). Yet, after having accounted for the distance to the equator and rainfall, the factor of sunshine became redundant. Our correlational data indicate that joyful connotations of yellow are stronger when temperatures are moderate and rainfall is ample. While sunshine might be positive, ample rainfall reduces otherwise harmful effects of heat and too much sunshine (e.g., droughts). These associations were driven by a country's typical annual climate and were not modulated by transient changes. We found that the number of daytime hours on the day of completing the survey did not influence the intensity of yellow-joy associations, suggesting minor seasonal effects on yellow-joy association.

The stability across seasons contrasts with previous studies on colour preferences, which vary systematically between autumn and the other seasons (Schloss et al., 2017). Potentially, colour preferences are more dynamic than colour-emotion associations, since preferences are shaped by one's personal and shared past affective experiences (Palmer & Schloss, 2010). This would explain why we found that yellow-joy associations varied with global climatological factors, but not with seasonal fluctuations.

Our results invite future research testing mechanisms by which climatological and geographical factors may impact colour-emotion associations. One could imagine that yellow-joy associations emerge because of an individual's experience (sunshine makes all colours more vibrant), physical sensations (the positive feeling of skin warmed by the sun), embodied experience (doing joyful things in the sunshine) or semantic pathways (talking about joyful things and sunshine together). Future studies should also investigate whether physical colour exposure impact psychological functions in systematic ways (e.g., yellow being a joy-inducing colour in participants living in warmer and rainier countries). While we acknowledge that many questions remain, our global study lays the groundwork for a better understanding of how the physical environment comes to shape the human mind.

Chapter 5.

Colour-Emotion Associations in Individuals with Red-Green Colour-Blindness [20]



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5.1. Abstract

Colours and emotions are associated in languages and traditions. Some of us may convey sadness by saying *feeling blue* or by wearing black clothes at funerals. The first example is a conceptual experience of colour and the second example is an immediate perceptual experience of colour. To investigate whether one or the other type of experience more strongly drives colour-emotion associations, we tested 64 congenitally red-green colour-blind men and 66 non-colour-blind men. All participants associated 12 colours, presented as terms or patches, with 20 emotion concepts, and rated intensities of the associated emotions. We found that colour-blind and non-colour-blind men associated similar emotions with colours, irrespective of whether colours were conveyed via terms (r = .82) or patches (r = .80). The colour-emotion associations and the emotion intensities were not modulated by participants' severity of colour blindness. Hinting at some additional, although minor, role of actual colour perception, the consistencies in associations for colour terms and patches were higher in non-colour-blind than colour-blind men. Together, these results suggest that colour-emotion associations in adults do not require immediate perceptual colour experiences, as conceptual experiences are sufficient.

5.2. Introduction

We *feel blue*, *see red*, and have some *black days*. As Westerners, we might wear *white* to weddings and *black* to funerals. These examples show that colours and affective meanings are associated in natural languages and cultural traditions. Moreover, colour-emotion associations are highly similar across cultures (Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Jonauskaite, Abu-Akel, et al., 2020; Ou et al., 2018). This similarity is indicative of a human psychological universal, which is a mental attribute shared by all or nearly all healthy human beings (see Norenzayan & Heine, 2005). This universal might be determined by conceptual knowledge, because emotion associations were similar when matched to colour patches or colour words, indicating that immediate colour perception is not necessary for these associations to be reported (Jonauskaite, Parraga, et al., 2020). To test this possibility, we recruited individuals with congenital red-green colour blindness. Such individuals have never seen colours in the same way as individuals with intact colour vision due to their congenital deficiencies (Linhares et al., 2008a). Yet, colour-blind individuals have been exposed to similar conceptual information, namely similar cultural and linguistic environments as non-colour-blind individuals (Byrne & Hilbert, 2010). If colour-emotion associations in the two groups are similar, irrespective of whether seeing colour patches or colour terms, we have good reasons concluding that conceptual colour-emotion associations are so well established that sufficient, and that immediate colour perception is not essential for such associations to be reported.

We are aware of several older and more recent studies investigating the extent to which colour-emotion associations are shared across cultures (Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Hupka et al., 1997; Jonauskaite, Abu-Akel, et al., 2020; Madden et al., 2000; Ou et al., 2018). Some studies reported cross-cultural similarities in, and even claimed universality for, associations between brighter colours and positivity (Specker et al., 2018), associations between colours and affective dimensions (Adams & Osgood, 1973; Gao et al., 2007; Ou et al., 2018), or colours and emotion terms (D'Andrade & Egan, 1974). Examples of these associations include *red* being an active, warm and strong colour, *blue*, *green*, and *white* being positive colours, dark colours being heavy while desaturated colours being passive. Other studies highlighted cross-cultural differences. For instance, *envy* was associated with *black*, *red*, *green*, *yellow*, or *purple* depending on the nation (Hupka et al., 1997). These studies, however, used different methods, usually testing a limited number of colours, emotions, and/or cultures.

Recently, Jonauskaite and colleagues (Jonauskaite, Abu-Akel, et al., 2020) tested 240 colour-emotion associations in 30 nations resulting from associations between 12 colour terms and 20 emotion concepts. For each colour term, participants were free to associate as many emotions as they felt appropriate, in their native language. Results revealed high similarity in the way colours and emotions were associated across nations (average correlation was r = .88). These cross-cultural results indicate that humans largely share how they associate colours with emotions, at least when colours are presented as terms. Presentation mode does not seem to matter, though, as similar emotions have been associated with colour patches, at least when participants were tested in a Western context. More precisely, in another study, Swiss adults again associated the 12 colours with the 20 emotion concepts (Jonauskaite, Parraga, et al., 2020). One group of participants associated emotions with basic colour terms and the other group with focal colours that best represent these basic colour terms. Both groups chose similar emotions for the same colour concepts, irrespective of whether they were presented as terms or patches (correlation between groups was r = .82). In a different study, Wang and colleagues (2014) reported high similarity in term-patch associations for *blue* but not *red*. In their study, Chinese participants evaluated r*ed* more positively as a term than a patch. Overall, with some potential exceptions, these results suggest that seeing a colour is not key to decide on colour-emotion associations, at least once individuals have reached adulthood.

High similarities in colour-emotion associations across cultures and presentation mode do not reveal the mechanisms that drive the formation of shared colour-emotion associations. Considering potential mechanisms, one mechanism might be shared perceptual experiences by most humans (see also, Palmer & Schloss, 2010; Jonauskaite et al., 2019a). In this case, a direct perceptual experience of colour might lead to an affective experience. For instance, looking at a colour would make one *feel* a certain emotion or immediately remind of a particular emotion. Another mechanism might be shared conceptual knowledge, accessed and transmitted through language (see Xu et al., 2013, for cultural transmission of colour terms). In that case, colours and emotions would be conceptually associated without necessarily meaning that immediate colour perception itself evokes associations with affective experiences.

To test the relative importance of conceptual versus immediate colour experience, we suggest for this study to test colour-emotion associations in populations with colour vision deficiencies. The most frequent colour vision deficiency is congenital red-green colour blindness. Here, affected individuals can discern a smaller number of colours than individuals with complete colour vision (Linhares et al., 2008a; Neitz & Neitz, 2000). Red-green colour blindness, also called Daltonism after John Dalton (Dalton, 1798), affects around 8% of the male population and around 0.6% of the female population of European-Caucasian origin (Birch, 2012; Sharpe et al., 1999). Such individuals confuse certain colours along the red-green axis (e.g., *red* and *brown*, *green* and *brown*, *pink* and *grey*, *grey* and *green,* etc.; Moreira et al., 2014) and likely see the world in bluish-yellowish colours (Byrne & Hilbert, 2010; Judd, 1949). Individuals with red-green colour blindness have never seen certain colours the way individuals with intact colour vision do, but have been exposed to their shared cultural and linguistic environments (e.g., traffic colours; Almustanyir & Hovis, 2020). Accordingly, if individuals with and without red-green colour blindness display similar colour-emotion associations, we can argue that shared conceptual knowledge is sufficient for colour-emotion associations to occur.

Studies assessing colour naming and colour arrangements support the importance of conceptual knowledge. In case of colour naming, colour-blind individuals were able to name colours indicating that they learned to differentiate colours, irrespective of whether they look the same or different to colours perceived by individuals with intact colour vision (Bonnardel, 2006; Jameson & Hurvich, 1978; Moreira et al., 2014; Nagy et al., 2014; Paramei, 1996). Bonnardel (2006) found that consensus in colour naming ranged between 52% and 74% for colour-blind and non-colour-blind individuals. The highest consensus emerged when participants had to name colour chips using one of eight colour terms (i.e., constrained colour naming task; 74% consensus). Some of the chips were focal colours (i.e., the best examples of each colour category) while others were not. The lowest consensus emerged for a task that least involved language (i.e., freely grouping colour chips into colour categories, 52% consensus). For colour arrangements, colour-blind individuals mentally arranged colours more similarly to non-colour-blind individuals when colours were presented as terms than as patches (Saysani et al., 2018b; Shepard & Cooper, 1992). When presented with terms, colour-blind individuals used three colour axes (i.e., red-green, blue-yellow, and dark-light) to arrange colours. When presented with patches of focal colours, colour-blind individuals collapsed colours along the red-green axis and used only two axes to arrange colours. Taken together, conceptual knowledge seems essential for colour naming and colour arrangements. Nonetheless, colour terms and colour patches might be treated somewhat differently by colour-blind individuals. If so, colour-blind individuals might also treat colour-emotion associations differently when actually reading a colour term or seeing a colour patch.

To test the importance of conceptual knowledge and immediate perceptual colour experience, we assessed 240 colour-emotion associations in individuals with and without red-green colour blindness using a previously established methodology (Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019). Part of each group associated emotion terms with colour terms while the remainder associated emotion terms with colour patches displaying focal colours. Emotion terms were presented in a circular format (Scherer, 2005; Scherer et al., 2013). We compared colour-emotion associations between colour-blind and non-colour-blind individuals as well as between colour terms and colour patches in each group. If shared conceptual knowledge is sufficient for colour-emotion associations to occur, we would expect high similarities in colour-emotion associations between individuals with and without colour blindness. We would also expect high similarity in colour-emotion associations between colour terms and colour patches in colour-blind individuals. If, however, previous or immediate perceptual colour experiences are necessary for consistent colour-emotion associations to occur, we would expect differences in colour-emotion associations between individuals with and without colour blindness (e.g., see Álvaro et al., 2015, for colour preferences). These differences should be more pronounced when actual perceptual colours (i.e., colour patches) rather than colour terms are evaluated, since perceptual colours appear differently to individuals with and without colour blindness (Byrne & Hilbert, 2010). We would also expect lower consistency between colour terms and colour patches in colour-blind individuals.

In addition to comparing colour-blind and non-colour-blind individuals, we further modelled colour blindness as a continuum. We tested whether the strength of colour blindness predicted colour-emotion associations. We chose to treat colour blindness as a continuum due to variations in physiological and behavioural expressions of colour blindness. Red-green colour blindness results from changes in the photopigments in the cone receptors coding for long ("reddish"; L-cones) or medium ("greenish"; M-cones) wavelengths (Parry, 2015). For some individuals, cones are completely missing (dichromatic vision), while for others, they are malfunctioning (anomalous trichromatic vision). The degree of perceptual confusion is related to the degree of individuals' physiological impairments (Neitz & Neitz, 2000). Many previous studies considered only individuals with dichromatic vision (Jameson & Hurvich, 1978; Moreira et al., 2014; Paramei et al., 1998; Saysani et al., 2018b; Shepard & Cooper, 1992). However, such individuals comprise just 28.5% of all colour-blind men of European origin (i.e., 2.3% of the general population of European males; Sharpe et al., 1999). Thus, we decided to freely sample from the colour-blind population and include both individuals with dichromatic vision and anomalous trichromatic vision (similar to, Bonnardel, 2006; Nagy et al., 2014; Paramei, 1996).

5.3. Materials and Method

5.3.1. Participants

We recruited 130 men, 64 were colour-blind by self-report, which was confirmed with colour vision tests (see *Colour Vision Tests* for further details). About half of the participants took part in the colour terms condition (associating terms with emotions, Table 5.1) and the other half took part in the colour patches condition (associating patches with emotions, Table 5.1). All participants lived in Switzerland. Most participants were either students or staff members of a local university. They were fluent French speakers, apart from one participant who was excluded from the analyses (see Table 5.1). Age did not differ between study groups, $F(3, 125) = 1.50$, $p = .218$.

Table 5.1. Demographic information of the colour-blind and non-colour-blind participants, divided by condition.

		N	Age		Gender	French fluency (max 8)	
			Mean	*SD*		*Mean*	*SD*
Colour terms condition	Colour blind	30	24.93	4.46	All males	8	0.00
	Non colour-blind	31	23.55	3.38	All males	8	0.00
Colour patches condition	Colour blind	34	22.56	5.71	All males	7.88	0.54
	Non colour-blind	34	23.53	3.95	All males	7.75	0.65

Based on a related previous publication, where we ran a 2 x 12 mixed-design MANOVA to compare emotion associations between terms and patches (Jonauskaite, Parraga, et al., 2020), we expected a large effect size ($V = .55$). We entered this effect size in the G*Power sample size calculator (Faul et al., 2007) together with the expected alpha (.05) and beta (.80) levels. We obtained 26 participants as a minimal total sample size. Yet, we decided to collect more participants to be able to also consider a variability in the expression of colour blindness as well as exclude weak colour-blind participants from part of the analyses.

Participation was voluntary and remunerated with monetary reward (CHF 20 in gift vouchers). The study was conducted in accordance with the principles expressed in the Declaration of Helsinki (World Medical Association, 2013). We received ethics approval from the local ethics board (C_SSP_032020_00003).

5.3.2. Colour Stimuli

We used *red, orange, yellow, green, turquoise, blue, purple, pink, brown, white, grey,* and *black* as colour stimuli. Eleven of these colour stimuli represent the principal colour categories (Biggam, 2012a). We also included *turquoise* because it covers the blue-green range. In the terms condition, colour stimuli were presented as French colour terms written in black ink (Spence, 1989, see Table S 15). In the patches condition, colour stimuli were presented as colour patches. Colour patches displayed the best exemplars of each colour category (i.e., focal colours, Table 3.1, Lindsey & Brown, 2014), and have been used in native French speakers in Switzerland (Jonauskaite, Parraga, et al., 2020).

5.3.3. Emotion Assessment

We used the Geneva Emotion Wheel (GEW 3.0; Figure 1.7; Scherer, 2005; Scherer et al., 2013) to measure emotion associations with colours. GEW is a validated self-report measure of the feeling component of emotion. Twenty emotion concepts are represented along the circumference of a wheel. These emotion concepts are organized along two axes. The horizontal axis represents *valence,* also known as evaluation or pleasantness (positive vs. negative). The vertical axis represents *power*, also known as control, dominance, or potency (strong vs. weak). Emotion concepts can further be categorised in terms of *arousal,* also known as activation (high arousal vs. low arousal), based on complementary research studies (Fontaine, 2013; Soriano et al., 2013). We reported this categorisation in a previous related study (Jonauskaite, Parraga, et al., 2020) and here in Table 1.1. Circles of increasing size connect the centre of the wheel with the circumference of the wheel. These circles denote five degrees of emotion intensity, coded from 1 (smallest circle; weakest intensity) to 5 (biggest circle;

strongest intensity), or 0 if no emotion is chosen (little square). The Swiss Centre for Affective Sciences provides the validated French version of the GEW (Table S 15).

5.3.4. Colour Vision Tests

Red-green colour blindness varies in severity. This variation can be behaviourally captured with colour vision tests. In this study, we used the Ishihara test (Ishihara, 2000), the Farnsworth test (Farnsworth, 1947), and the Lanthony test (Lanthony, 1978a, 1978b). Detailed information regarding testing and scoring of the three behavioural tests appears in Supplementary material. These and other similar behavioural tests do not seem to rely on higher cognitive functions. Rather, they rely on the discrimination of primary visual features, since they have been successfully used to assess colour vision in other animal species (e.g., dogs, seals; Scholtyssek et al., 2014; Siniscalchi et al., 2017).

5.3.5. Procedure

We performed the colour terms and colour patches conditions as similarly as possible, but had to also account for the different study material. The procedure was identical to a previous study (Jonauskaite, Parraga, et al., 2020). Below, we detail what was comparable for conditions (see *Common to Both Conditions*), followed by the description of the terms condition procedure and the patches condition procedure.

Common to Both Conditions

Upon arrival to the welcome room, we gave participants relevant study information. Those who agreed to participate signed the written informed consent form (see Figure 5.1 for procedure). Next, we tested participants' colour vision with the Ishihara test. All colour vision tests were conducted as physical tests under the same conditions of artificial office light. Afterwards, participants were invited to the testing room. The computer monitor was the only source of illumination in the testing room. All participants performed the experiment on the same monitor: Eizo ColourEdge CG247 24.1" (inches) LCD display, with an in-built self-calibration sensor. We set the temperature of the monitors to 6500 K, gamma: 2.2, contrast: 100%, and brightness: 120cd/m^2. Resolution was 1920 x 1200 pixels and the frame rate was 59.90 Hz. The eye-screen distance was approximately 70 cm.

Participants completed either the terms or the patches condition. Experimenters were available for questions at any point during the experiments. After the main experiment, participants returned to the welcome room and completed the Farnsworth D-15 and Lanthony D-15 tests. These tests were given in a randomised order across participants. Once participants completed the first test, the completed test was hidden and they were asked to complete the second test. Upon the completion of both tests, participants were debriefed and remunerated. Participants were invited to ask questions and received a debriefing sheet with written information and contact details for future references. The entire experiment took between 50 and 70 minutes.

Colour Terms Condition

The colour terms condition was performed in the laboratory testing room. We used an existing online survey link (https://www2.unil.ch/onlinepsylab/colour/main.php); also used to collect data remotely for a larger ongoing International Colour-Emotion Survey online (Jonauskaite, Abu-Akel, et al., 2020; Mohr et al., 2018). In the current experiment, participants accessed the online survey on our laboratory computer to ensure comparability between the two experimental conditions.

The survey started with an information page. On the next pages, the task was explained, namely to associate colour terms with emotion concepts, presented on the GEW (see *Emotion Assessment*). Participants had to perform a manipulation check exercise to make sure they understood the task. In particular, participants had to correct the responses of an imaginary person (Peter). In the following experimental part, participants saw the 12 colour terms written in black ink on a grey background, presented sequentially and in random order above the GEW (see *Colour stimuli* and Table 3.1). Participants were asked to choose one, several, or none of the GEW emotion concepts that they associated with each colour term. They also rated intensities of each associated emotion by choosing circles of different sizes, which were later coded as 1-5 ratings. After the colour-emotion association task, participants provided demographic information and saw results from a previous related marketing experiment in graphic format.

Colour Patches Condition

We performed the colour patches condition in the same laboratory testing room as the terms condition. The experiment started with an information page explaining the task, namely to associate colour patches with emotion concepts, presented on the GEW (see *Emotion Assessment*). Participants proceeded to the next page if they understood the task. Then, three example colours followed. For the examples as well as for the main task, participants were presented with a colour patch (15° x 15° subtended angle) on a neutral grey background (see Table 3.1). They were instructed to focus on the colour patch. Participants chose when to move to the subsequent page but no earlier than 5 seconds after it appeared on the screen. On each subsequent page, in analogy to the terms condition, participants associated one, several, or none of the GEW concepts with the target colour patch and rated the intensity of each associated emotion concept. While associating emotions, participants could see the target colour on the small GEW squares as well as on the chosen intensity circles (Figure 5.1.B Experiment 2). There were 12 experimental colour patches presented in randomised order (see *Colour stimuli* and Table 3.1). Colour values were adapted for the monitor (see *Apparatus* in Supplementary material). We collected these data in the laboratory to ensure accurate colour presentation.

After the colour-emotion association task, participants completed the colour-naming task with the same colour patches. Each colour patch was presented 12 times in randomised order and paired with one of the colour terms (total of 144 presentations). Participants had to evaluate how likely they would be using this *colour term* to name a particular *colour patch* from "not at all" (converted to 0) to "very likely" (converted to 100). For example, participants would see a *green* colour patch and have to respond how likely they would be to call it *purple.* Not all participants in the patches condition performed the colour-naming task (22 colour-blind and 33 non-colour-blind completed the task). We decided to add this task after the first 10 colour-blind participants had been tested. After these two tasks, participants provided demographic information, analogous to the terms condition, on a paper questionnaire.

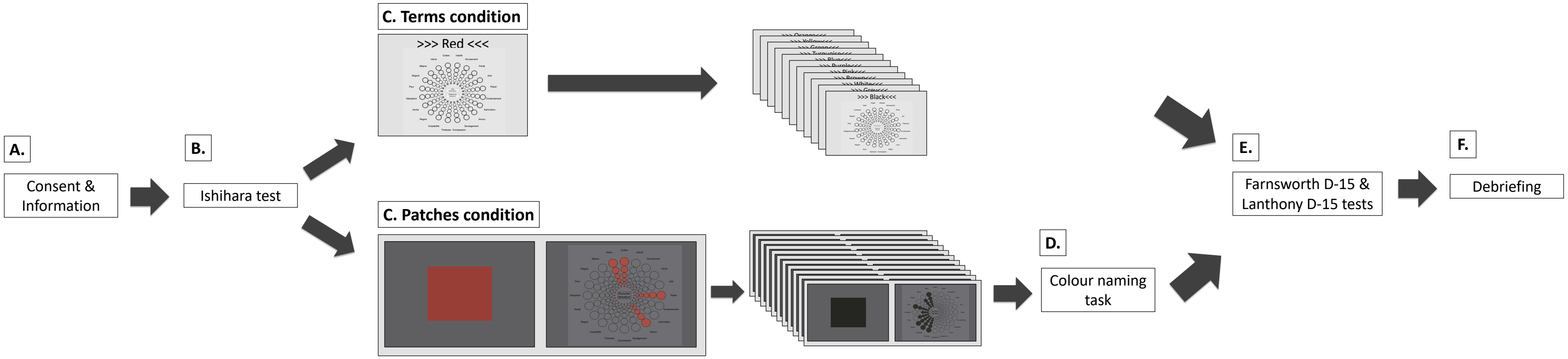

Figure 5.1. Procedure for the colour terms and colour patches conditions in Chapter 5.

(A) Participants received written study information and signed informed consent. (B) Participants completed the Ishihara test. (C) Main experiment. In Experiment 1, participants saw 12 colour terms in randomised order. They associated colour terms with one, several, or none of the Geneva Emotion Wheel (GEW) emotion concepts (see *Emotion assessment* and Figure 1.7 for enlarged GEW). In the patches condition, participants saw 12 colour patches in randomised order. They associated colour patches with one, several, or none of the GEW emotion concepts on the subsequent screen. Here, they saw the small GEW squares as well as the GEW rays of chosen emotion concepts presented in the colour they were currently evaluating. In both conditions, participants answered demographic questions. (D) In the patches condition, most participants also performed a colour-naming task. (E) Participants completed the Farnsworth D-15 and Lanthony D-15 tests in random order. (F) Participants were debriefed.

5.3.6. Data Preparation

The raw data can be accessed following this link: https://forsbase.unil.ch/project/study-public-overview/16969/0/. We cleaned the data based on colour blindness scores by creating the Colour Blindness Index.

Colour Blindness Index

We used errors on the colour blindness tests to create a single measure of colour blindness – the *Colour Blindness Index*. This index served a dual purpose. First, we could ensure accurate participant re-categorisation into colour-blind and non-colour-blind participants. Second, we obtained a continuous measure of colour blindness.

To determine the colour blindness indices, we used a principal component analysis on the correlation matrix of the number of errors on the Ishihara test, the number of crossing errors on both the Farnsworth D-15 and Lanthony D-15 tests, and the number of neighbour errors on both the Farnsworth D-15 and Lanthony D-15 tests (see Supplementary material for scoring). The principal component analysis resulted in two factors with Eigenvalues greater than 1 (i.e., 2.79 and 1.07 respectively for factors 1 and 2). The first factor explained 55.7% of the variance and the second factor explained an additional 21.3% of the variance. The first factor separated the colour-blind participants from the non-colour-blind participants, and we called this factor the colour blindness index (see Figure S 6A). The second factor was difficult to interpret and did not separate participants by colour blindness (see Figure S 6B). Thus, we disregarded it. In Table S 29, we present the loadings of each item for both factors.

The visual inspection of the frequency distribution of the colour blindness index (Figure S 6A) indicates that it might consist of three different distributions. The most leftward distribution (< -0.6) included only non-colour-blind participants plus one colour-blind participant by self-report. Thus, the latter participant was most likely not colour-blind; he passed both the Farnsworth D-15 and Lanthony D-15 tests, and was categorised as “unsure” on the Ishihara test. The most rightward distribution (> 0.2) included only colour-blind participants by self-report, thus, these participants had relatively strong colour blindness. The intermediate distribution (between -0.6 and 0.2) included both self-reported colour-blind and non-colour-blind participants. Participants with these scores might have (very) weak colour blindness or no colour vision impairment but nevertheless made errors for other reasons (e.g., inattentiveness).

For the group-level analyses (see below), we considered only the two extreme groups (i.e., re-categorised non-colour-blind and re-categorised colour-blind participants). Such a categorisation ensured that participants grouped in the non-colour-blind group were indeed not colour-blind (had low colour blindness index scores) while participants grouped in the colour-blind group were indeed relatively strongly colour-blind (i.e., had high colour blindness index scores)[21]. There were 25 colour-blind and 25 non-colour-blind participants in the terms condition. There were 24 colour-blind and 31 non-colour-blind participants in the patches condition (see Table S 30).

5.3.7. Data Analyses

We ran the subsequent analyses using these new and improved colour blindness categories. We set alpha levels for all tests at .050. All analyses were two-tailed. Across statistical tests, where appropriate, we controlled for familywise errors (Type I error) using False Discovery Rate (FDR) correction and marked the corrected *p*-values as p_{FDR} (Benjamini & Hochberg, 1995). We performed analyses and created graphs with the R v.3.4.0 and SPSS v.25.

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[21] We chose the most inclusive limits. This allowed us to keep as many "real" non-colour-blind and "real" colour-blind participants as possible. However, less inclusive boundaries (i.e., excluding everyone who scored between -0.7 and 0.4 on the colour blindness index) did not change the overall results of our analyses and the respective conclusions. Please find the complete dataset at https://forsbase.unil.ch/project/study-public-overview/16969/0/

Group-Level Analyses

For these analyses, we compared the re-categorised non-colour-blind and colour-blind participants, as described in the section *Colour Blindness Index*. We continue labelling them colour-blind and non-colour-blind participants, for simplicity.

Specific Colour-Emotion Associations. We started the analyses by investigating the specific emotion concepts associated with colours. We calculated the proportion of participants who associated a specific emotion concept with a specific colour by dividing the number of participants who chose each emotion concept for each colour by the total number of participants in that group (e.g., colour-blind, terms condition). The proportion of participants was calculated separately for colour-blind participants and non-colour-blind participants for each condition (terms or patches) separately. The proportion values were the dependent variable, which varied from 0 (very unlikely association, no one chose it) to 1 (very likely association, everyone chose it).

To compare the *pattern* of emotion associations, we created four 12 x 20 (colours x emotions) representation matrices using the proportion values to compare colour blindness groups and colour presentation modes. $Matrix_{CB\text{-}term}$ contained colour-emotion associations of colour-blind participants associating colour terms with emotion concepts, while $Matrix_{Non\text{-}CB\text{-}term}$ contained analogous associations of non-colour-blind participants (terms condition). $Matrix_{CB\text{-}patch}$ contained colour-emotion associations of colour-blind participants associating colour patches with emotion concepts while $Matrix_{Non\text{-}CB\text{-}patch}$ contained analogous associations of non-colour-blind participants (patches condition; see Figure 5.2).

Then, we used Pearson matrix correlations to compare $Matrix_{CB\text{-}term}$ vs. $Matrix_{Non\text{-}CB\text{-}term}$ and $Matrix_{CB\text{-}patch}$ vs. $Matrix_{Non\text{-}CB\text{-}patch.}$ These matrix correlations formed the basis for the Pattern Similarity Index (PSI), which reflects the degree of similarity in the pattern of colour-emotion associations between two matrices. A PSI score of 1 indicates perfect pattern similarity, and a PSI score of 0 indicates complete pattern dissimilarity. Furthermore, to compare the similarity of emotion associations for each colour, we calculated PSI_{colour}. PSI_{colour} was estimated per colour using Pearson correlations between colour-blind participants and non-colour-blind participants, and between colour terms and colour patches.

To identify which colour-emotion associations differed between colour-blind and non-colour-blind participants, we further used Fisher's exact tests (Fisher, 1922). The test compared the proportion of participants endorsing a particular colour-emotion association (yes/no; n = 240) between colour-blind and non-colour-blind participants for terms and for patches separately. All comparisons were FDR corrected (Benjamini & Hochberg, 1995).

Emotion Intensity. The dependent variable *emotion intensity* was calculated by averaging intensity ratings assigned to emotion concepts associated with each colour and for any colour (i.e., "overall"). Emotion intensity varied from 1 (weak) to 5 (strong), unless no emotion concept was chosen (coded as missing value).

A 2 x 2 independent-samples ANOVA compared average *emotion intensity* of all colours together (i.e., "overall") between re-categorised study groups (colour-blind vs. non-colour-blind) and conditions (colour terms vs. colour patches). Afterwards, series of independent-samples *t*-tests compared *emotion intensity* ratings per colour between colour-blind and non-colour-blind participants for terms and for patches separately, and between terms and patches for colour-blind and non-colour-blind participants separately. All comparisons were FDR corrected (Benjamini & Hochberg, 1995).

Supplemental Analyses. Additionally, we analysed colour associations with emotion dimensions and colour naming. As these were supplementary analyses, the method and results are presented in the Supplementary material.

Individual-Level Analyses

We tested whether the *presence* of colour-emotion associations depended on the degree of colour blindness (i.e., colour blindness index). To this end, we fitted a multilevel logistic model, accounting for repeated measures, using *glmer* function in lme4 package (Bates et al., 2015). We used the likelihood ratio test to test for significance of individual predictors and their interactions. The predictor variables were the colour blindness index, colour presentation mode (2 levels, independent), colour (12 levels, repeated), and emotion (20 levels, repeated). We also tested for the three interactions between the colour blindness index and i) colour presentation mode, ii) colour, and iii) emotion. The outcome variable was presence of colour-emotion association (yes/no). These analyses were performed on all participants (*n* = 129).

5.4. Results

5.4.1. Colour Blindness Scoring

The 2 x 2 MANOVA on the number of errors in colour blindness test scores indicated that colour-blind participants made significantly more errors than non-colour-blind participants on all tests. However, their performance did not differ by condition (terms or patches). More details are presented in the Supplementary material and Table S 31.

5.4.2. Group-Level Analyses

Specific Colour-Emotion Associations

Some colour-emotion associations were prominent in both study groups. For instance, *red-love*, *red-anger*, *yellow-joy*, *pink-love* and *brown-disgust* were chosen by 50% or more of colour-blind as well as non-colour-blind participants (terms and patches combined). The majority of colour-blind participants also associated *orange* with *joy*, *yellow* with *pleasure*, and *blue* with *pleasure*. The majority of non-colour-blind participants also associated *red* with *pleasure*, *red* with *hate*, *yellow* with *amusement*, *turquoise* with *joy* and *pleasure*, *blue* with *interest*, *pink* with *joy* and *pleasure*, *grey* with *sadness* and *disappointment,* and *black* with *fear*. See Figure 5.2 for visual representation of all colour-emotion associations (and supplemental tables for the numeric values: Table S 36, Table S 17, Table S 18, and Table S 39).

Colour-Blind Vs. Non-Colour-Blind Participants. After having described the specific colour-emotion associations, we compared the pattern of colour-emotion associations between study groups and conditions. The matrix correlations, PSI, were overall high. PSI comparing emotion associations with colour terms ($\text{Matrix}_{\text{CB-term}}$ vs. $\text{Matrix}_{\text{Non-CB-term}}$) showed high similarity, $r = .82$, $R^2 = .672$, $p < .001$, and so did PSI comparing emotion associations with patches ($\text{Matrix}_{\text{CB-patch}}$ vs. $\text{Matrix}_{\text{Non-CB-patch}}$), $r = .80$, $R^2 = .637$, $p < .001$ (see Figure 5.2). These correlation coefficients were of similar strength, $z = -0.63$, $p = .529$. These results imply that colour-blind participants and non-colour-blind participants associated similar emotions, irrespective of whether a colour was presented as a term or a patch.

Furthermore, colour-specific PSI_{colour} comparing emotion associations between colour-blind and non-colour-blind participants for each colour were high for colour terms, r = .60-.97, R^2 = .355-.939, p_{FDR} < .006, and for colour patches, r = .55-.92, R^2 = .548-.924, p_{FDR} < .012, see Table 5.2. The only exception was *purple*, for colour terms, r = .07, R^2 = .004, p_{FDR} = .781, and for colour patches, r = .09, R^2 = .007, p_{FDR} = .721. These results indicate that the similarity between colour-blind and non-colour-blind participants held across all colours, whether a term or a patch was presented, with *purple* being an exception.

Fisher's exact tests were used to identify any differences between the specific colour-emotion associations between the two study groups, separately for each condition. No specific colour-emotion comparisons were significant suggesting that no colour-emotion specific association differed between the two study groups (p_{FDR} ≥ .39). Thus, despite low correlations for *purple*, we could not detect specific emotion associations driving this dissimilarity.

Colour Terms Vs. Colour Patches. Furthermore, we compared the pattern of emotion associations with colour terms and colour patches, respectively, for each study group separately. The matrix-to-matrix correlations, PSI, were again overall high. PSI comparing emotion associations between colour terms and colour patches in colour-blind participants ($Matrix_{CB\text{-}term}$ vs. $Matrix_{CB\text{-}patch}$) showed high similarity, r = .74, R^2 = .552, p < .001, and so did PSI comparing emotion associations between colour terms and colour patches in non-colour-blind participants ($Matrix_{Non\text{-}CB\text{-}term}$ vs. $Matrix_{Non\text{-}CB\text{-}patch}$), r = .83, R^2 = .683, p < .001 (see Figure 5.2). However, the correlation coefficient in colour-blind participants was significantly lower than in non-colour-blind participants, z = -2.59, p = .010. These results mean that similar emotions were associated with colour terms and with colour patches by non-colour-blind participants as well as by colour-blind participants, but the latter did so to a lower extent.

Furthermore, colour-specific PSI_{colour} comparing emotion associations between colour terms and colour patches for each colour were high for colour-blind participants, r = .46-.89, R^2 = .214-.795, p_{FDR} < .040, and for non-colour-blind participants, r = .49-.96, R^2 = .243-.929, p_{FDR} < .027, see Table 5.2. The exception again was *purple*, associations of which did not correlate for colour-blind participants, $r = .26$, $R^2 = .066$, $p_{FDR} = .273$. Correlations for *green* in colour-blind participants were significant but low ($p = .040$). These results indicated that the similarity between colour terms and colour patches was equally true for colour-blind and non-colour-blind participants, with the exception of *purple*.

Fisher's exact tests were used to identify differences for specific colour-emotion associations between conditions, separately for colour-blind and non-colour-blind participants. No specific colour-emotion comparisons were significant ($p_{FDR} \geq .57$). Thus, despite a low correlation in colour-blind participants between *purple* as a patch and as a term, we could not detect specific emotion associations driving this dissimilarity.

Table 5.2. Matrix-to-matrix correlations per colour (PSI_{colour}).

It is separated by correlations between colour-blind and non-colour-blind participant association matrices, and between colour terms and colour patches association matrices. The PSI_{colour} (correlation coefficient *r*) indicates the similarity between two matrices with 1 indicating perfect similarity. All *p*-values are FDR corrected for multiple comparisons; * $p < .050$, ** $p < .010$, *** $p < .001$.

	Colour blind vs. Non-colour-blind		Terms vs. Patches	
	Terms	Patches	Colour-blind	Non-colour-blind
Red	0.88***	0.85***	0.84***	0.82***
Orange	0.85***	0.77***	0.83***	0.85***
Yellow	0.84***	0.90***	0.83***	0.88***
Green	0.80***	0.55*	0.46*	0.76***
Turquoise	0.83***	0.92***	0.87***	0.95***
Blue	0.97***	0.86***	0.84***	0.96***
Purple	0.07	0.09	0.26	0.69**
Pink	0.90***	0.87***	0.89***	0.95***
Brown	0.79***	0.82***	0.82***	0.84***
Grey	0.91***	0.76***	0.86***	0.89***
White	0.60**	0.88***	0.75***	0.49*
Black	0.92***	0.86***	0.67**	0.68**

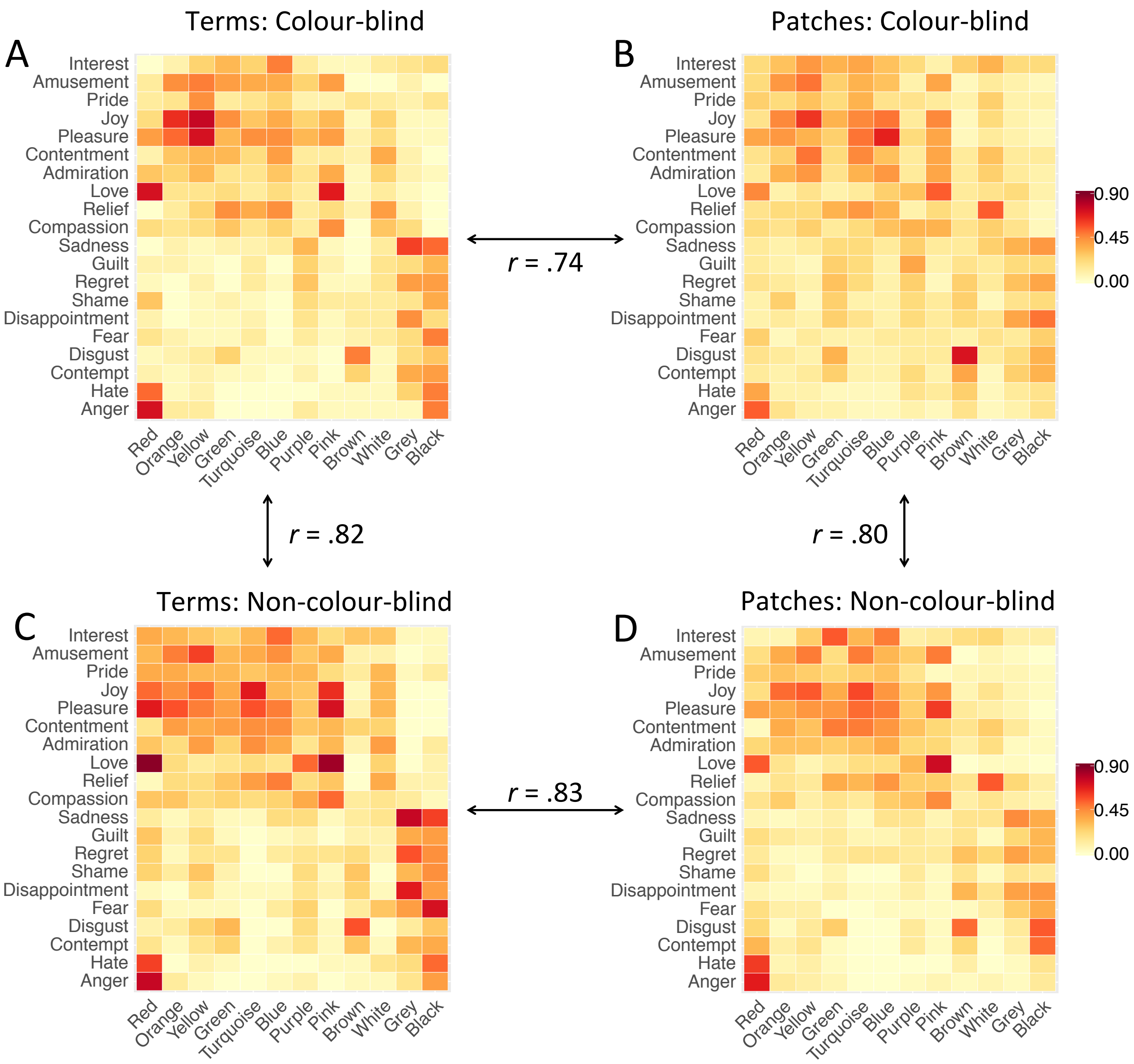

Figure 5.2. Heatmaps of colour-emotion associations of colour-blind and non-colour-blind participants.

(A) Colour-emotion associations with colour terms in colour-blind participants; (B) Colour-emotion associations with colour patches in colour-blind participants; (C) Colour-emotion associations with colour terms in non-colour-blind participants; (C) Colour-emotion associations with colour patches in non-colour-blind participants. Redder cells indicate higher proportions of participants choosing specific colour-emotion associations.

Emotion Intensity

The 2 x 2 ANOVA revealed a significant main effect of condition, $F(1, 101) = 14.8$, $p < .001$, $\eta_p^2 = .123$, indicating that more intense emotions were associated with colour terms than colour patches by both study groups. There was no significant main effect of study group, $F(1, 101) = 2.44$, $p = .121$, $\eta_p^2 = .024$, indicating that colour blind and non-colour-blind participants associated equally intense emotions overall. Finally, the interaction between study group and condition was not significant, $F(1, 101) = 0.23$, $p = .440$, $\eta_p^2 = .006$. For differences by colour, see supplemental material (Table S 32, Table S 33, Table S 34, and Table S 35).

5.4.3. Individual-Level Analyses

The multilevel logistic regression model was overall significant, $LR(63) = 876$, $p < .001$, ${}_{pseudo}R^2 = .028$ (Cox & Snell), .047 (Nagelkerke). Both, colour, $LR(12) = 161$, $p < .001$, ${}_{pseudo}R^2 = .005$ (Cox & Snell), .009 (Nagelkerke), and emotion, $LR(20) = 675$, $p < .001$, ${}_{pseudo}R^2 = .022$ (Cox & Snell), .037 (Nagelkerke), were significant predictors of whether colours and emotions were associated or not. In contrast, the colour blindness index was not a significant predictor of the probability of colour-emotion associations, $LR(1) = 0.03$, $p = .865$, ${}_{pseudo}R^2 < .001$ (Cox & Snell), < .001 (Nagelkerke). Hence, the probability of colour-emotion associations did not vary by degree of colour blindness. Condition was not a significant predictor either, $LR(1) = 0.14$, $p = .711$, ${}_{pseudo}R^2 < .001$ (Cox & Snell), < .001 (Nagelkerke).

The two-way interaction between the colour blindness index and colour was significant, $LR(11) = 23.4$, $p = .016$, ${}_{pseudo}R^2 = .001$ (Cox & Snell), .001 (Nagelkerke). Higher colour blindness index resulted in lower probability of emotion associations with *red*, $\beta = -0.17$, $z = -2.08$, $p = .037$. However, this effect was weak and disappeared after FDR correction ($p_{FDR} = .44$). The colour blindness index was not a significant predictor for other colours, $ps_{FDR} = .96$. The other two-way interactions between the colour blindness index and emotion, $LR(19) = 9.58$, $p = .96$, ${}_{pseudo}R^2 < .001$ (Cox & Snell), < .001 (Nagelkerke), and the colour blindness index and condition, $LR(1) = 1.73$, $p = .189$, ${}_{pseudo}R^2 < .001$ (Cox & Snell), < .001 (Nagelkerke), were not significant.

Given these zero results, we wished to estimate the likelihood that, indeed, the colour blindness index is unlikely to predict the probability of colour-emotion associations. We examined the key predictor of interest (colour blindness index) by estimating the Bayes factor using Bayesian Information Criteria (Jarosz & Wiley, 2014; Wagenmakers, 2007). The Bayes factor compared the fit of the data under the null hypothesis with the fit of the data under the alternative hypothesis. The estimated Bayes factor (null/alternative; BF_{01}) was 245:1, suggesting that the data were 245 times more likely to occur under the null hypothesis than the alternative hypothesis. Reversely, the data were 0.004 times more likely to occur under the alternative than the null hypothesis (BF_{10}).

5.5. Discussion

Colours are associated with emotions (Adams & Osgood, 1973; Fugate & Franco, 2019; Kaya & Epps, 2004; Schloss et al., 2020; Tham et al., 2019; Valdez & Mehrabian, 1994; Wexner, 1954) and these associations might be universal across cultures (Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Jonauskaite, Abu-Akel, et al., 2020; Ou et al., 2018). If the assumption on universality holds true, we have to ask whether these associations originate from our shared i) conceptual, abstract understanding of the world (Xu et al., 2013), or ii) perceptual experience of inhabiting the globe (Palmer & Schloss, 2010). Recently, Jonauskaite, Parraga, et al. (2020) showed that colour-emotion associations were similar for colour patches and colour terms in young Swiss adults. These results indicate that i) conceptual colour experiences seem sufficient for colour-emotion associations to occur, and ii) immediate perceptual colour experiences do not seem necessary.

To further assess these suggestions, we tested men with congenital red-green colour blindness as well as men with intact colour vision. We tested men, because they have a much higher incidence of colour blindness than women (Birch, 2012; Sharpe et al., 1999). Our participants associated 12 colours with 20 emotion terms, and rated the emotion intensities (see also Jonauskaite, Parraga, et al., 2020). Half of our participants associated colour terms, and the other half associated colour patches. Participants who associated colour patches also named them. We found that colour-blind and non-colour-blind men showed a high degree of similarity in colour-emotion associations, whether associating colour terms or colour patches. In case of colour patches, the two groups named colours almost identically. Furthermore, the strength of colour blindness neither predicted colour-emotion associations nor emotion intensities. Within group comparisons showed highly similar emotion associations with terms and patches (see also Jonauskaite, Parraga, et al., 2020, with yet a higher similarity found in non-colour-blind than colour-blind men.

Before discussing these major findings, we highlight that we tested representative samples. We replicated common colour-emotion associations such as *red-love, red-anger, yellow-joy, pink-love,* and *brown-disgust* associations (Fugate & Franco, 2019; Jonauskaite, Abdel-Khalek, et al., 2019; Jonauskaite, Abu-Akel, et al., 2020; Kaya & Epps, 2004). When we clustered the 20 emotion concepts into the affective dimensions of valence, arousal, and power, we replicated that *black*, *grey*, and *brown* were negative colours; *yellow*, *orange*, *blue*, *turquoise*, *pink*, and *white* were positive colours; and *red* was an arousing and powerful colour associated with both positive and negative emotions (Adams & Osgood, 1973; Jonauskaite, Parraga, et al., 2020; Lakens et al., 2012; Soriano & Valenzuela, 2009; Specker et al., 2018; Sutton & Altarriba, 2016b; Valdez & Mehrabian, 1994). These colour-emotion associations were endorsed by both colour-blind and non-colour-blind men.

When returning to our major findings, we have to first remember that colour-blind individuals perceive colours differently from non-colour-blind individuals since birth (Linhares et al., 2008a). They have diminished or completely absent excitations of the L or M photoreceptors (Dalton, 1798; Parry, 2015). Second, we have to remember that colour-blind individuals have learned the same conceptual representations of colour as non-colour-blind individuals (Byrne & Hilbert, 2010), including colour naming (Bonnardel, 2006, and the current study). With these pieces of information in mind, we can start considering what it might mean that our colour-blind and non-colour-blind participants provided highly similar colour-emotion associations, despite partially different perceptual experiences. First of all, participants likely activated similar abstract colour representations when reading a colour term (e.g., *red*) to when looking at the actual colour patch. Then, we can also consider that the colour-emotion associations were more majorly driven by the conceptual representations of colours, because seeing actual colour patches seemed to carry no additional information to colour-emotion associations (see also, Jonauskaite, Parraga, et al., 2020). The latter consideration echoes analogue notions for colour-tone associations (Saysani, 2019), transmission of colour terms (Xu et al., 2013), mental colour spaces (Saysani et al., 2018b, 2018a; Shepard & Cooper, 1992), or object-colour knowledge (X. Wang et al., 2020). So far, we have to limit our reasoning to colour-emotion associations for focal colours, which we presented here, and which are highly recognisable by colour-blind men (see also, Moreira et al., 2014).

So far, we have discussed the high similarities between groups and conditions. However, the degree of similarities fell short of 100%, leaving space for additional variance to be explained. Part of this variance might be random noise, but part might be linked to meaningful individual differences. In this regard, the degree of colour blindness was uninformative; it did not explain colour-emotion associations or emotion intensities. We observed, however, that the similarity of emotion associations with terms and patches was less pronounced for colour-blind than non-colour-blind men. This relatively lower similarity points to a possible influence of actual colour experiences to colour-emotion associations (see also, Saysani et al., 2018b; Shepard & Cooper, 1992). One could suggest that colour-blind men as compared to non-colour-blind men were less certain when naming colour patches. This suggestion seems unlikely, however, because colour-blind and non-colour-blind men named the patches of focal colours almost identically. Alternatively, due to perceptual deficiencies, colour-blind men who saw colour patches might have activated slightly different abstract colour representations than colour-blind men who read colour terms, especially for colours affected by colour blindness. We found that colour-blind men showed the lowest patch-term similarities for *purple* and *green,* and associated more intense emotion concepts with *red*, *orange*, *yellow*, *pink*, *black*, and *white* when colours were presented as terms than patches (see also Jonauskaite, Parraga, et al., 2020, for stronger emotion intensities with terms than patches). Also, colour-blind men associated fewer emotion concepts with *red* than non-colour-blind men. Colour-blind men might have imagined these colours more vividly than seen in patches, associating more intense and specific emotions when processing these terms.

Overall, our observations on high degrees of similarities support the previous literature, showing high similarities in colour-emotion associations across cultures (Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ou et al., 2018). At the same time, studies have also shown systematic variations on long-term and short-term scales. On long-term scales, high similarities in colour-emotion associations were more pronounced when individuals came from nations that were linguistically and/or geographically closer (Jonauskaite, Abu-Akel, et al., 2020). For instance, individuals living closer to the equator had a lower likelihood to associate *yellow* with *joy* than individuals living further away from the equator (Jonauskaite, Abdel-Khalek, et al., 2019). Studies have also shown systematic variations on shorter time scales. Individuals living in the same nation preferred autumn-like colours more strongly in autumn than during other seasons of the year (Schloss et al., 2017; Schloss & Heck, 2017). On even shorter time scales, colour preferences have been influenced in a laboratory experiment (Strauss et al., 2013). These authors showed that exposure to numerous positive objects (e.g., strawberries and wine) increased the liking of the respective colour (e.g., *red*), while exposure to numerous negative objects (e.g., a bloody nose and rotten tomatoes) decreased the liking of the respective colour (e.g., *red*). Likely, studies showing such systematic variations demonstrate the human species' abilities to adapt to particularities of their respective environments (Lupyan & Dale, 2016).

As an auxiliary finding, we observed a low similarity in emotion associations with *purple.* We observed dissimilar associations between colour-blind and non-colour-blind men as well as between terms and patches in colour-blind men. Colour-blind men associated *purple* with diverse positive as well as negative emotions, while non-colour-blind men associated *purple*, especially as a term, with positive emotions, mainly with *love*. Diverse findings for *purple* are not new. Participants in general disagree which emotions *purple* represent, whether data originate from the same nation (Fugate & Franco, 2019; Hemphill, 1996; Sandford, 2014; Sutton & Altarriba, 2016b; Wexner, 1954), from four or 30 nations (Hupka et al., 1997; Jonauskaite, Abu-Akel, et al., 2020), or when comparing terms and patches (Jonauskaite, Parraga, et al., 2020), as was also done here. We suggest that this lack of clarity for *purple* is an interesting observation, so much so that it deserves its own investigation (e.g., Hamilton, 2014; Oja & Uusküla, 2011; Tager, 2018).

5.5.1. Strengths and Limitations

There are numerous strengths and limitations to our study. The first strength is that we employed the same method used previously to assess colour-emotion associations (Griber et al., 2019; Jonauskaite, Abdel-Khalek, et al., 2019; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Dael, et al., 2019; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019). This consistency simplifies direct comparisons between studies. The second strength is that we recruited a large number of congenitally colour-blind men, at least when comparing our sample size to previous studies (Álvaro et al., 2015, 2017; Bonnardel, 2006; Moreira et al., 2014; Paramei et al., 1998; Paramei, 1996; Sato & Inoue, 2016; Saysani et al., 2018b; Shepard & Cooper, 1992). By default, a larger sample size provides more representative colour-emotion associations.

Yet, having a larger sample size for our colour-blind men also meant that our sample was relatively diverse (see also, Bonnardel, 2006; Nagy et al., 2014; Paramei, 1996). We recruited all men who had self-reported congenital red-green colour blindness, irrespective of its strength. Thus, we tested men with partial as well as complete colour vision deficiencies (i.e., dichromatic and anomalous trichromatic vision), with mainly deutan-like or unidentified impairments. Only some previous studies aimed for a sample of exclusively dichromatic participants (e.g., Álvaro et al., 2015, 2017; Moreira et al., 2014; Shepard & Cooper, 1992), resulting in a much smaller number of tested individuals.

To factor in this diversity and to account for varying strength of colour blindness, we derived the Colour Blindness Index from scores on three behavioural colour vision tests (Farnsworth, 1947; Ishihara, 2000; Lanthony, 1978a). This Colour Blindness Index was not a significant predictor of colour-emotion associations, while between- as well as within-group similarities were high. Therefore, we argue that differences in colour perception within our colour-blind group bore little relevance to colour-emotion associations, at least when working with highly recognisable focal colours. If this conclusion holds true, similar colour-emotion associations should also arise in congenitally blind individuals. Previous studies have demonstrated that congenitally blind individuals possess similar mental spaces of colour (Saysani et al., 2018a), associate similar colours with pure tones (Saysani, 2019), and represent object-colour knowledge in similar brain regions as sighted individuals (X. Wang et al., 2020). Some blind individuals also associate similar colours with semantic scales, but there is high a variability among the blind (Saysani et al., 2021).

Another potential limitation is the use of focal colours (i.e., best examples of colour categories) and basic colour terms, both of which are overlearned. Testing colour patches that are difficult to name or using non-basic colour terms, like *lavender* or *mauve*, would be the next step in this type of research. Such colour stimuli might be more powerful to reveal more differences between colour-blind and non-colour-blind individuals. The perceptual experience might be more important when working with stimuli that are less overlearned. In a previous study (Saysani et al., 2018b), the mental arrangement of non-basic colour terms was less similar between colour-blind and non-colour-blind individuals than the mental arrangement of the basic colour terms. Yet, the similarity between the two groups was still very high in both conditions, suggesting that colour-blind participants have a common understanding of non-basic colour terms too.

5.5.2. *Theoretical and Practical Implications*

All results considered, we conclude that cultural knowledge, transmitted through language, plays a sufficient role for colour-emotion associations to occur, while immediate perceptual colour experience in adulthood does not seem to be necessary. This conclusion has implications to theories in which the importance of colour perception to affective associations with colour is highlighted (Hurlbert & Ling, 2007; Palmer & Schloss, 2010; Schloss, 2018). According to the cone-opponent theory (Hurlbert & Ling, 2007), human colour preferences are influenced by weights on the two cone-opponent contrast components (i.e., L-M; S-(L+M)). According to the Ecological Valence Theory (Palmer & Schloss, 2010), human colour preferences are driven by the valence of objects of the same colour. For instance, people like colours that are associated with positive objects and dislike colours that are associated with negative objects. As an example, *blue* would be liked because it is associated with clear sky and clean water while *brown* would be disliked because it is associated with rotten food. Note, these theories have been developed to explain colour preferences and not colour-emotion associations (but see Schloss, 2018). Perhaps, colour preferences and colour-emotion associations are guided by different mechanisms. In fact, colour preferences have been hypothesised (Schloss, 2015) and empirically demonstrated (Álvaro et al., 2015; Baek et al., 2015; Sato & Inoue, 2016) to differ between colour-blind and non-colour-blind individuals. More specifically, colour-blind individuals preferred *yellowish* colours to a greater extent and *bluish* colours to a lesser extent than non-colour-blind individuals (Álvaro et al., 2015). Colour preferences seem also less universal (Groyecka et al., 2019; Schloss & Palmer, 2017; Taylor, Clifford, et al., 2013). Thus, immediate perceptual experiences might be more relevant to colour preferences than to colour-emotion associations. Alternatively, future theories should account for more conceptual, knowledge- and language-based factors when explaining colour preferences (see Yokosawa et al., 2016 for the importance of symbolic colour associations to colour preferences).

If immediate perceptual experiences are not necessary for colour-emotion associations in adulthood, then research on colour-emotion associations might not easily translate to applied domains. For instance, proponents of colour therapy, or chromotherapy, assume that perception of colour can impact one’s affective states (Azeemi & Raza, 2005; Gul et al., 2015; O’Connor, 2011; Winkler, 2012). Often, such claims are based on conceptual colour associations. One can read, “Being the lightest hue of the spectrum, the colour psychology of yellow is uplifting and illuminating, offering hope, happiness, cheerfulness and fun” (Scott-Kemmis, 2018b). *Yellow* was indeed conceptually associated with *joy* in 55 countries (Jonauskaite, Abdel-Khalek, et al., 2019). However, an association between *yellow* and *joy* does not immediately imply that looking at *yellow* walls or *yellow* objects would make one feel *joyful*. Empirical studies have struggled to confirm many of the expected psychological effects of colour, such as *pink* reducing aggressiveness in prisoners (Genschow et al., 2015), or *pink*, *red*, or *blue* enhancing cognitive performance and improving mood (von Castell et al., 2018). A recent study also demonstrated that direct exposure to colour was not important to stress and anxiety reduction following a colour intervention (Jonauskaite, Tremea, et al., 2020). In short, conceptual colour-emotion associations should not be equated with and might not translate to psychological consequences of colour.

5.6. Conclusions

We evaluated whether conceptual mechanisms are sufficient for consistent colour-emotion associations to emerge or whether immediate colour experience is necessary We found that colour-emotion associations were highly similar between individuals with congenital red-green colour blindness and individuals with intact colour vision. This high similarity was observed whether colours were shown as terms or patches. Based on our findings, we conjecture that intact immediate colour vision is not necessary for colour-emotion associations, at least not in adulthood. Likely, these associations are driven by conceptual mechanisms, our language and knowledge. In other words, it is unlikely that colour-emotion associations arise exclusively from direct affective experiences when seeing colours, because conceptual knowledge is already well established. To reason one step further, high similarities between colour-blind and non-colour-blind individuals as well as similarities across cultures (Adams & Osgood, 1973; Jonauskaite, Abu-Akel, et al., 2020) would suggest that colour-emotion associations present another human psychological universal (Norenzayan & Heine, 2005).

Chapter 6.

General Discussion

Popular and scientific opinions hold that colours have psychological and affective consequences. In this thesis, I focused on the associations between two seemingly disparate properties – colours and emotions – and questioned how common these associations were. By testing their stability across nations, colour presentation modes, and perceptual conditions, I aimed to understand if such associations are fundamental to the human mind or are shaped by cultural and linguistic customs and/or perceptual experiences. In all studies, participants from different countries and/or populations associated 12 colours (terms or patches) with 20 emotion concepts and rated intensity of the associated emotions. All participants performed the task in their native languages.

In the first two empirical chapters, I assessed universality across nations and colour presentation modes. In Chapter 2, participants came from 30 nations (n = 4,598) and evaluated colour terms (Jonauskaite, Abu-Akel, et al., 2020). In Chapter 3, Swiss participants (n = 132) evaluated either colour terms or colour patches (Jonauskaite, Parraga, et al., 2020). In the last two empirical chapters, I assessed the importance of perceptual experience on a group level (physical environment) and an individual level (colour vision) to colour-emotion associations. In Chapter 4, participants, currently living in one of 55 countries (n = 6,625), evaluated the association between *yellow* and *joy* (Jonauskaite, Abdel-Khalek, et al., 2019). In Chapter 5, Swiss men with or without red-green colour-blindness (n = 130) evaluated colour terms or colour patches (Jonauskaite et al., 2021). Our results showed a high degree of universality, further shaped by linguistic, perceptual, and geographic factors. Below, I discuss the results of each chapter and present common conclusions. Afterwards, I consider the broader context, theoretical and methodological implications of these results.

6.1. Empirical Chapters and Conclusions

6.1.1. Chapter 2: Universal Patterns in Colour-Emotion Associations

In Chapter 2, we assessed the degree of similarity in the pattern of colour-emotion associations across 30 nations. After comparing associations of each nation with a global pattern of associations (i.e., all nations except the nation in question), we found a high degree of similarity (mean r = .88, range = .68-.94), vouching for universality. High congruency between nations was also achieved on other measures such as an average probability of any colour-emotion association and intensity of the associated emotions. These universal colour-emotion association patterns were further shaped by participants' linguistic and geographic environments but did not differ by gender or age. That is, participants living geographically closer to each other or speaking more linguistically related languages associated colours with emotions in a more similar manner. Likewise, the machine-learning algorithm confused these nations to a greater extent. We concluded that colour-emotion associations are built on a universal basis further modulated by language and geography.

6.1.2. Chapter 3: Similar Pattern of Emotion Associations with Colour Patches and Colour Terms

In Chapter 3, we assessed whether colour-emotion associations were stable across different colour presentation modes (colour terms or patches). The similarity between the two colour presentation modes was high (r = .82) as participants associated similar emotions with colour terms and colour patches with all but *purple*. Colours did not show differences in their connotations of valence, arousal, or power or in their emotion intensity ratings. The only other colour that differed between terms and patches was *black*. It did not, however, differ in terms of *which* emotions were associated but in the *degree* of the association. *Black* was evaluated more negatively as a term than a patch and was associated with several negative emotions to a greater extent (*sadness, regret, hate,* and *anger*). These emotions were also rated as more intense for a term than a patch. Overall, we conjectured that colour terms and colour patches were associated with largely similar emotions and so colour-emotion associations are stable across different colour presentation modes. This is true at least when comparing emotion associations with focal colours and basic colour terms.

6.1.3. Chapter 4: Physical Environments Affect How We Feel About Yellow

In Chapter 4, we tested whether colour-emotion associations remain stable and universal with variations in environmental conditions. We focused on *yellow-joy* associations, which conceivably arise because *yellow* is reminiscent of life-sustaining sunshine and pleasant weather. By testing participants from 55 nations, we revealed consistent *yellow-joy* associations across nations with the likelihood of associations varying as a function of climatological and geographic factors. Participants were more likely to associate *yellow* with *joy* if they currently lived i) further away from the equator, and ii) in climates with higher annual levels of precipitation. However, the *yellow-joy* association did not vary as a function of daylight hours, suggesting that environmental influences are rather constant and do not vary by seasons. These results indicate that the degree of *yellow-joy* association was influenced by one's experience of local physical environments above and beyond the observed universal tendencies in these associations[22]. We hope that we and others can find systematic relationships for other colour-emotion associations and different ecological factors (e.g., positivity of *green* and lush environments).

6.1.4. Chapter 5: Colour-Emotion Associations in Red-Green Colour-Blindness

In the final empirical chapter, we assessed the importance of individuals' perceptual colour experience for colour-emotion associations. We compared colour-emotion associations in

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[22] The publication that forms the basis for this chapter received a commentary letter short after its first appearance online (Azer, 2020). The major concern expressed in this commentary was the lack of culture-specific explanations with reference to colour metaphors. Our reply (Jonauskaite & Mohr, 2020) highlighted that colour metaphors seem limited in their potential to understand and explain colour-affect relationships.

individuals with partial colour vision (i.e., red-green colour blind) with those of matched non-colour-blind individuals. In line with the procedure described in Chapter 3, participants associated emotion concepts with either colour terms or colour patches. We found a high degree of similarity in colour-emotion associations between participants with and without colour-blindness (*r's* = .82 & .80 for terms and patches respectively). We observed no differences for valence, arousal, and power dimensions, and few differences for emotion intensities (e.g., colour-blind participants evaluated emotions associated with *red*, *orange*, *pink*, *yellow* and *white* as more intense when the latter were a term than a patch). The strength of colour blindness did not predict the likelihood of colour-emotion associations. Nonetheless, perceptual experience might be somewhat important as colour-blind individuals showed a slightly lower consistency in term-patch associations than non-colour-blind individuals. Taken together, these results indicate that colour-emotion associations were stable irrespective of differences in colour vision. We concluded that conceptual knowledge seemed sufficient for colour-emotion associations to exist and direct perceptual experience plays a secondary role, at least when testing basic terms and focal colours.

6.1.5. Common Conclusions

In all four chapters, we observed a high degree of similarity and stability, leading to three main conclusions. First, the patterns of colour-emotion associations are universal. Second, these patterns are further modulated by perceptual and linguistic experiences. Third, colour-emotion associations are conceptual and abstract in nature, or at least, conceptual processing is sufficient to have these associations when testing basic colour terms and focal colours. In other terms, colour-emotion associations are stable across different environmental conditions as well as invariant across colour presentation modes (terms or patches).

Importantly, such universals do not imply that individuals agree 100%. Some disagreement gives scope for dynamic adaptations to immediate and lasting changes in one's environment. We have seen that colour-emotion associations were influenced by linguistic and geographic factors, as well as perceptual experiences, as term-patch consistency was lower in the colour-blind. Hence, universality in colour-emotion associations is relative and it allows for additional culture-specific and person-specific colour meanings. We suggest that universal colour-emotion associations facilitate non-verbal transfer of information between individuals within and between nations. The transfer should be higher for individuals living in neighbouring nations or speaking related languages. The observed universal goes in line with the known universal and relative features in the domains of colour and emotion, presented in the Supplemental Material (see Universality in The Domains of Colour and Emotion).

Systematic colour-emotion associations now provide a baseline to develop theoretical considerations and stimulate studies that target more specific questions. In the sections below, I introduce the **Colour Connotation Theory**, which aims to organise existing knowledge about colour-emotion associations. Using this theory, I suggest some mechanisms that might drive colour-emotion associations and suggest how affective colour connotations might relate to behaviour. I also consider colour connotations more broadly, and reason how colour-emotion associations are related to other constructs (preferences, cross-modal associations, symbolism). I close the General Discussion by recognising strengths and limitations of the current studies, and by suggesting avenues for future research.

6.2. The Proposal of the Colour Connotation Theory

In this section, I propose the **Colour Connotation Theory** to link different pieces of information in order to better understand colour-emotion associations (see Figure 6.1 for visual display). The theory helps identifying potential mechanisms driving colour-emotion associations, understanding how colour connotations might impact behaviour, and formulating hypotheses for future studies.

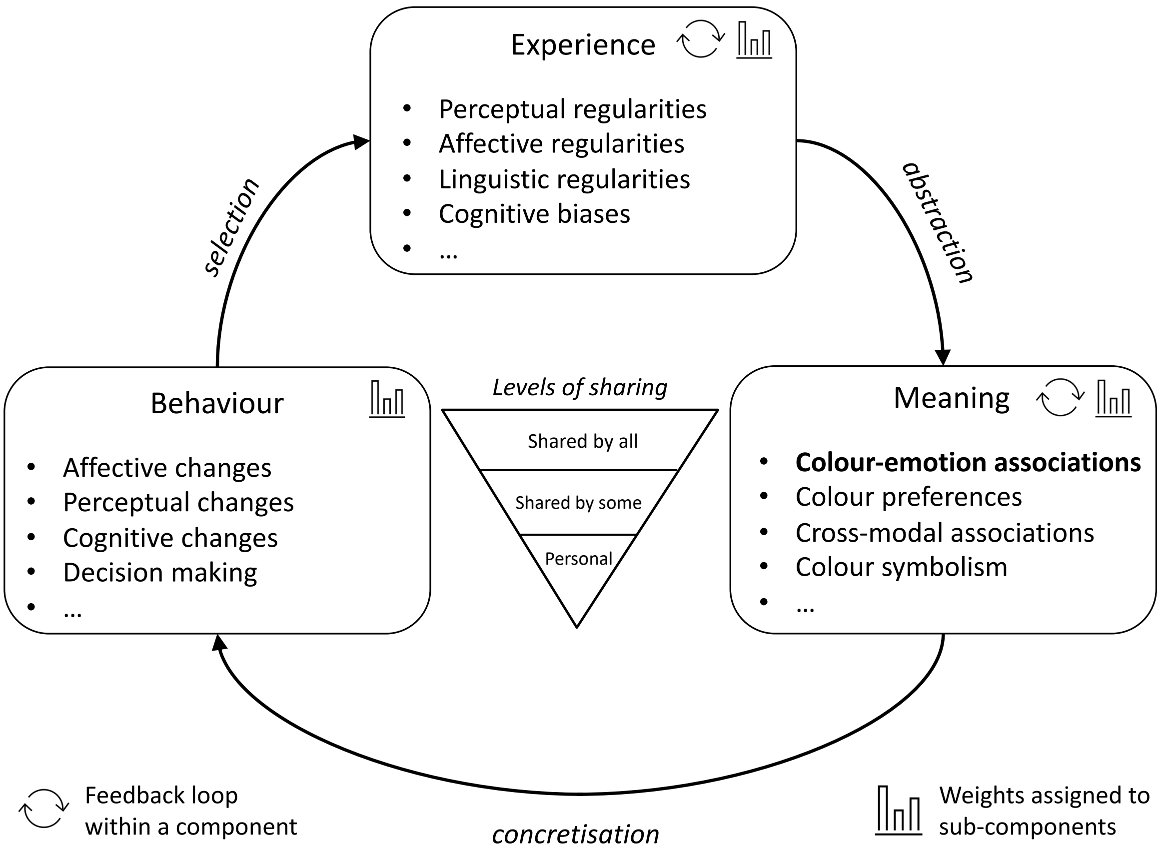

Figure 6.1. The schematic representation of the Colour Connotation Theory, proposed in Chapter 6.

There are three components in this model: Experience, Meaning, and Behaviour. Experience is driving Meaning through weighing the sub-component and their abstraction and conceptualisation. Meaning is impacting Behaviour through weighing the subcomponents and their concretisation and contextualisation. Behaviour impacts Experience through selection. The sub-components in Experience and Meaning components influence each other through feedback loops. These components and their sub-components may function on a shared-by-all, shared-by-some or personal levels, which respectively explain universal, relative, and individual aspects of colour connotations.

6.2.1. Overview of the theory

Components and Sub-Components

There are three key components in the Colour Connotation Theory. The first component is **Experience**, which includes all types of human experiences that could lead to colour connotations (meanings). I grouped these experiences into the following sub-components: i) **perceptual environment**; ii) **affective environment**; iii) **linguistic environment**; and iv) **cognitive biases**. I propose that frequencies of exposure (statistical regularities) to these experiences drive colour connotations.

The second component is **Meaning**. The Meaning component includes all the different colour connotations, including but not limited to **colour-emotion associations, colour preferences, colour symbolism, cross-modal correspondences**. While the main focus of my thesis is on colour-emotion associations, the scientific literature reports on diverse other colour connotations. The connotations are important when considering colour meaning overall, and they may shape colour-emotion associations.

The third component is **Behaviour**. The Behaviour component encompasses different colour-related behaviours and decisions. I grouped these under the following sub-components: i) **affective changes**, ii) **perceptual changes**, iii) **cognitive changes**, and iv) **decision making**. This component is broad, because colours are thought to have a wide range of psychological and affective consequences. Conceptual colour connotations might drive these presumed consequences.

The Relationship Between the Components

I linked the three components of the Colour Connotation Theory in a **circular fashion** (see Figure 6.1). This circularity should help thinking about the mechanisms driving colour connotations and how colour connotations influence one's affective and psychological states, choices and behaviours. I propose that Experience is driving Meaning, Meaning is impacting Behaviour, and Behaviour is feeding back to Experience. While Experiences and Behaviour are concrete, Meaning is abstract and conceptual. Thus, Meaning is shaped by extracting statistical regularities in perceptual, affective, linguistic, and cognitive experiences. The human mind weighs the importance of each type of regularity and constructs specific colour connotations. Behaviour arises as a consequence of Colour Meaning. When exposed to a situation, an appropriate Colour Meaning is selected, concretised, contextualised, and applied to suit a specific situation. An individual has access to their different abstract colour connotations and correspondences and selects the one that is most appropriate to impact behaviour. Finally, the consequences of one's Behaviour cause new Experiences, which can then shape anew Meanings, and so on. Furthermore, within each component, there is a **feedback loop** via which the different sub-components inform and influence each other (e.g., positive emotion associations might be favoured for pleasant colours).

Levels of Information Sharing

I suggest that all the components of the Colour Connotation Theory function at three levels of sharing: **shared-by-all**, **shared-by-some**, and **personal** (see Figure 6.1). Experiences that are shared by all might explain universal tendencies in colour connotations and behaviours. Experiences that are shared by some might explain why certain connotations are relative and specific to cultures and groups of individuals. Finally, experiences that are personal might explain why some connotations are unique. Similarly, colour connotations that are shared by all might lead to universally observed behaviours while connotations that are shared by some might lead to relative and specific behaviours. In Table 6.1, I suggest some concrete examples on these relationships.

Table 6.1. Hypothesised relationships between Experience, Meaning, and Behaviour on the three levels of sharing.

Level of sharing	Experience	Meaning	Behaviour
Shared by all	Blue sky and water	- Preference for blue - Positive emotion associations with blue	Trusting companies with blue logos*
Shared by some (culture-specific)	Purple as a funeral colour (in Greece)	Purple-sadness association	Avoiding purple for happy events
Shared by some (time-specific)	Yellowish-brownish foliage in autumn	Increased preference for yellowish-brownish colours	Wearing yellowish colours
Personal	Childhood bedroom coloured in orange	Positive associations with and preference for orange	Buying orange personal objects

* *Note*. universality has not been demonstrated; this is just a suggestion based on the literature

6.2.2. Experience

Here, I am mainly focusing on how statistical regularities in our experiences could give rise to *colour-emotion associations*. However, these regularities likely impact other colour connotations too, including cross-modal correspondences (C. Spence, 2011) and colour preferences (Palmer & Schloss, 2010; Schloss, 2018).

Perceptual Regularities

I suggest two mechanisms for how statistical regularities in *perceptual environments* could drive colour-emotion associations. The mechanisms are frequent pairings between i) visual colours and perceived emotions and ii) visual colours and affective situations.

If we think about **pairings between visual colours and perceived emotions**, we can extract changes in others' affective states from changes in facial colouration. In the case of *red* and *anger*, irrespective of skin colour, blood rushes to a person's face when getting angry, making it look redder (Benitez-Quiroz et al., 2018). This relationship likely explains why redder faces are evaluated as angrier (Thorstenson et al., 2020). A change in facial colouration is, thus, an efficient mechanism to transmit and decode emotion (Benitez-Quiroz et al., 2018; Nakajima et al., 2017). However, reddening of the face is not a reliable indicator of the exact emotion the other person is experiencing. It only helps to distinguish emotions in terms of affective dimensions [23]. To infer the exact affective state from others' facial colouration, one must

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[23] For instance, faces look redder not only when experiencing anger but also when feeling embarrassed ("blushed") (Keltner & Buswell, 1997). In an experimental setting, participants increased redness in faces displaying anger, happiness, and surprise and decreased redness in faces displaying fear, disgust, and sadness (Thorstenson et al., 2018). In another study, although with bodily and not facial expressions of emotions, participants matched redder and yellow colours to elated joy than panic fear (Dael et al., 2016). Thus, the same perceptual stimulus, such as a reddened face, may lead to different interpretations of affective states.

extract additional information from the surrounding context (also see the Colour in Context theory in Elliot & Maier, 2007, 2012; Meier et al., 2012).

If we think about **pairings between visual colours and affective situations**, *black* is a common colour for funerals and mourning in the Western world. Seeing *black* at funerals might reinforce its associations with *sadness* and *grief,* that are shared by all. The link might also be reinforced through memory or imagination of a particular situation. In countries, where different funeral colours are predominant, colour-emotion associations are slightly different too. In Greece, *purple* is a frequent colour for funerals and so *purple* was commonly associated with *sadness* by Greek participants (Chapter 2 and Jonauskaite, Wicker, et al., 2019).

Other colours also sometimes appear in specific affective situations. *White* is worn for weddings signalling *happiness* but it is also prevalent in hospitals, indicating *cleanliness*, *purity, relief,* and *compassion* (Evarts, 1919; Jonauskaite, Abu-Akel, et al., 2020; Kaya & Epps, 2004). *Red* is used for Valentine's day decorations or dating, reinforcing associations with *love* and *passion*. In China, *red* is a popular colour for a wedding dress and for wedding decorations. Seeing red in these happy celebrations might reinforce the link between red and positivity (T. Wang et al., 2014) and explain why *red* was associated with *joy* more strongly in China than in other countries (Chapter 2 and Jonauskaite, Wicker, et al., 2019). That said, colour-related customs vary largely across countries, while the culture-specific component in colour-emotion associations seems relatively minor. Thus, colour-related customs explain only a part of colour-emotion associations.

Affective Regularities

I suggest a mechanism for how statistical regularities in *affective environments* could drive colour-emotion associations, namely **regularities in affective experiences when exposed to particular visual colours**. For instance, *joy* might become associated with *yellow* or *orange* if people feel happy when emerged in sunshine or when looking at a crackling fireplace. The example of *black* as a funeral colour also applies here, knowing that a person attending funeral is likely to be feeling sad.

While it seems plausible that affective experience when exposed to colours would eventually lead to conceptual colour-emotion associations, scientific support is rather weak. In particular, empirical studies struggled to report systematic and reliable physiological changes in response to colour. Several studies demonstrated that warm as compared to cool colours increased heart rate (AL-Ayash et al., 2016), skin conductance (Jacobs & Hustmyer Jr, 1974; Wilson, 1966) or EEG responses (Küller et al., 2009) but others did not observe measurable differences between these colours (Caldwell & Jones, 1985; Jacobs & Hustmyer Jr, 1974; Litscher et al., 2013; Pressey, 1921; Wilms & Oberfeld, 2018). Wilms and Oberfeld (2018) concluded that saturation and brightness were better predictors of physiological arousal than hue (see also, Pressey, 1921), leaving it possible that affective regularities might still play a role in the formation of colour-emotion associations.

Linguistic Regularities

I suggest two mechanisms to explain how statistical regularities in *linguistic environments* could drive colour-emotion associations. These mechanisms are i) co-occurrence of colour and emotion terms in natural languages, and ii) colour metaphors.

If we think about frequent **co-occurrences of colour terms and emotion terms**, one finds that colour terms are embedded in written and spoken texts nearby other words that carry emotional connotations. The latter words might create biases in the cognitive maps of colour terms and shape colour-emotion associations. For example, Steinvall (2007) systematically assessed English collocations of colour and affect from the Bank of English language corpus. In the majority collocations, when counted per colour, *black* appeared close to *sadness*, *white* close to *anger* and *fear*, *red* close to *anger*, *yellow* close to *joy*, *green* close to *anger*, *blue* close to *joy*, *grey* close to *sadness*, *pink* close to *love* and *joy*, *orange* close to *joy* and *purple* close to *anger*. Some of these co-occurrences were similar to colour-emotion associations reported in Table 1.4 and this thesis[24], supporting the idea that such a mechanism is probable.

If we think about **colour metaphors**, linguistic constructs where one domain is mapped onto another domain (e.g., *feeling blue*, *light up one's life,* etc.), numerous metaphors relating colour and affect exist in English (Allan, 2009; Sandford, 2014) and other languages (Al-Adaileh, 2012; Aliakbari & Khosravian, 2013; Cacciari et al., 2004; G. He, 2011; Iljinska & Platonova, 2017; Kalda & Uusküla, 2019; Philip, 2006; Rodriguez Redondo & Molina Plaza, 2007; Sirvydė, 2007). For instance, the omnipresent association between positivity and lightness also manifests in numerous metaphoric expressions like *bright day, white lie, dark thoughts,* and *black market* (Allan, 2009)[25]. According to the conceptual metaphor theory (Lakoff & Johnson, 1999), metaphorical links between abstract concepts, like affect, and more concrete perceptual experiences, like colour, help one understand and verbalise their affective experiences. Once a metaphoric mapping becomes ingrained in a language, speakers use the metaphoric construction without even being aware of its metaphoric nature.

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[24] In another more recent study, Jonauskaite, Sutton, et al. (2021) extracted valence and gender biases from Wikipedia articles containing 6 million words with 400,000 unique entries. Their study showed that all colour terms were biased towards positivity, and *blue*, *green*, and *pink* were used in more positive contexts than 95% of 100,000 common words.

[25] Sandford (2014) systematically gathered colour-emotion metaphors from two linguistic databases (COCA and COHA), adding to 850 million words in total. She reported that the most frequent emotions metaphorically associated with *white* were fear and shock, with *black* – anger and furry, with *red* – rage and embarrassment, with *yellow* – fear and worry, with *green* – envy and jealousy, with *blue* – pride and envy, with *grey* – exhaustion and remorse, with *brown* – anger, with *purple* – rage and anger, and with *pink* – embarrassment and excitement. Other metaphors relating colour and emotion include *feeling blue* (feeling sad), *yellow-bellied* (being coward), *seeing red* (angry), *green-eyed* (jealous), or *turn green* (envious) (Allan, 2009).

While some of these metaphorical associations mirror known colour-emotion associations, others do not. If we take *yellow* as an example, empirically, *yellow* was associated with *joy* across at least 55 countries (see Table 1.4 and Chapter 4). Yet, there is no equivalent metaphorical expression that would link *yellow* with *joy*, at least not in English, German, French, Lithuanian, Dutch, or Spanish. Rather, yellow is metaphorically associated with negative emotions in different languages. To be *yellow-bellied* means to be cowardly or easily scared; *Gelb vor Neid sein* [be yellow with envy] means to be envious in German; and *rire jaune* [laugh yellow] signifies forced laughter to hide embarrassment in French (also see Jonauskaite & Mohr, 2020, for further discussion). Thus, the role of colour metaphors in the formation and transmission of colour-emotion associations is yet uncertain and likely minor.

Cognitive Biases

Finally, cognitive biases transmitted though cultural learning and language might be another mechanism guiding colour-emotion associations. Some might compare the forces guiding cultural learning with the forces guiding biological evolution (see Dawkins, 1976, on **memes** and genes). For instance, an analogous force to mutation might explain how culture changes over time due to errors in learning and cognitive biases. Xu and colleagues (2013) demonstrated experimentally how such a force might influence learning of colour categories [26] and similar forces might guide the learning of colour-emotion associations.

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[26] Xu and colleagues (2013) suggested that individuals teach other individuals the meaning of colour terms through iterative learning. In their experiment, they had 13 “generations” of learners. The first participant saw 330 Munsell chips and was taught between two to six pseudo-words to name the entire spectrum of colours. The location of Munsell chips named with the same pseudo-word was random. Once the first participant learnt to name all the Munsell chips, they were asked to teach the next participant the mapping between the same pseudo-words and colour chips. This learning chain was continued for 13 participants to simulate 13 “generations” of learners, and it was repeated 30 times. While each learning chain started with an unnatural partitioning of the colour space, with each generation of learners, the space was partitioned more and more “naturally”. The final partitioning

Feedback Loop Within the Experience Component

Perceptual, affective, linguistic, and cognitive experiences are not modular. They do not occur in isolation but rather interact with and reinforce each other. If we take colour metaphors, one might consider them to function purely on a linguistic level. And yet, many colour metaphors have perceptual underpinnings (Meier & Robinson, 2005). The metaphorical expression *seeing red* (i.e., feeling angry) also has a perceptual basis – as we learned above for the angry face being flushed with blood and thus being redder. In this regard, we cannot decide whether *red-anger* associations became reinforced through linguistic and/or perceptual regularities. Similarly, perceptual and affective experiences might occur together, as in the example of *black*. The understand how different experiences influence each other, one must experimentally manipulate availability or absence of one of the sub-components while assessing colour-emotion associations.

Understanding Mechanisms Driving Colour-Emotion Associations

Perceptual Experience. One way to investigate if visual/perceptual experiences of colour could be driving colour-emotion associations is by assessing these associations in individuals with reduced colour vision. In Chapter 5, we tested red-green **colour-blind** individuals. However, colour-blind individuals do see colours, even if the perceived spectrum of colours is reduced (Byrne & Hilbert, 2010; Moreira et al., 2014). It has been argued that colour-blind individuals, and especially those, who have weaker forms of colour blindness (e.g., who have deuteranomaly instead of deuteranopia) can use the remaining available visual information of colour to distinguish and categorise nearly all colours (Byrne & Hilbert, 2010; Moreira et al., 2014). Future studies could test other types of partial colour-blindness (e.g., tritanopia) as well

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came relatively close to the partitioning of the space in languages that have only two to six basic colour terms (see Figure S 9).

as complete colour-blindness (i.e., achromatopsia). Alternatively, studies could focus on colours that are difficult to distinguish (e.g., brown-red, blue-purple; Moreira et al., 2021).

Furthermore, to establish whether visual experience has any added benefit for colour-emotion associations, or whether they function purely on a conceptual level, one must eliminate the visual component completely. This could be achieved by testing colour-emotion associations in the **blind**, ideally by further separating congenitally blind (i.e., blind from birth) and late-blind people. For the congenitally blind, colours are purely abstract concepts, and for the late-blind, colours are distant memories. Thus, the blind cannot rely on current visual experience when estimating affectivity of colours. Instead, they must judge the affectivity in relation to what they have learnt about colours and the associated concepts (e.g., *red – blood – anger*). Late-blind people might be able to rely on the memory of colours. Separating congenitally and late-blind people would indicate whether past visual experience has any importance for the formation of the associations between colours and emotions. Studies have shown that blind individuals have knowledge about colours and can form complex associations with them, similarly to the sighted (Marmor, 1978; Saysani et al., 2018a; Shepard & Cooper, 1992; X. Wang et al., 2020). Studies have only started to understand how blind associate colours with tone (Saysani, 2019) or semantic scales (Saysani et al., 2021).

Another way to test the importance of visual experience is by assessing colour-emotion associations in **different ecological environments**. The latter might be important in several ways. First, colours lacking from one's environment might be appreciated to a greater extent. They might be associated with more positive emotions and/or liked to a greater extent. Indeed, Himba people, a small-scale society in Namibia, liked colours that were rare in their environment (Taylor, Clifford, et al., 2013). Second, colours that are abundant in one's environment might become less strongly associated with corresponding emotions (i.e., a habituation effect), as shown for *yellow-joy* associations in Chapter 4. Third, other colours that are abundant yet irritating might become more strongly associated with negative emotions and become less liked over time (i.e., a sensitisation effect). One could imagine that *grey* becomes more negative in countries with a high degree of cloud coverage, if the latter provokes negative experiences. To better understand these effects, future studies should study people living in unconventional environments, like deserts (including arctic deserts), steppes, tundra, or rainforests.

Affective Experience. So far, there is not much evidence that direct affective experience with colours is important for colour-emotion associations in adulthood. Nonetheless, it is possible that such an experience was important during development, when colour-emotion associations were forming and shaping. Testing associations early in life would reveal if there are any biological mechanisms underlying colour-emotion associations. Reactions to colour can be measured as early as at two months of age with the preferential looking paradigm, which is usually interpreted as measuring colour preferences [27]. While it is not trivial to link infant colour preferences and colour-emotion associations [28], when a successful paradigm is used, similarities in colour-emotion associations in pre-linguistic infants as compared to older individuals could provide evidence in favour of perceptual, or even innate, mechanisms of colour-emotion associations. Of course, studies with older children and even adolescents could also be informative as abstract thinking and semantic associations develop with age (Dumontheil, 2014).

Linguistic Experience. Considering that colour-emotion associations are largely conceptual and abstract in nature (see Chapters 3 and 5, also Saysani, 2019; Tham et al., 2019), linguistic experience might prove crucial for the formation and existence of these associations. In parallel

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[27] Several studies suggested that infants look longer at *red*, indicating they prefer this colour over others (Franklin et al., 2008, 2010, 2012; Jadva et al., 2010; Taylor, Schloss, et al., 2013; Zemach et al., 2007). When compared to adult colour preferences, infants show a different preference pattern than adults (Taylor, Schloss, et al., 2013), but not always (A. E. Skelton & Franklin, 2019).

[28] In one attempt to link colour preferences and colour-emotion associations, Franklin and colleagues (2012) measured infant preferential looking patterns after exposure to happy or angry faces. In both cases, infants preferred *red* and *blue* over *green*. This finding disproved a potentially innate association between *anger* and *red*, as the two were not preferentially associated.

to testing restricted colour vision (i.e., colour-blind or completely blind individuals), one could also test restrictions to colour vocabulary. The size of colour vocabulary could be understood in two ways: i) the number of basic colour terms in a language, and ii) the number of non-basic colour terms known by an individual.

The number of basic colour terms varies across languages from just two to eleven, twelve, or even more. Studying speakers of languages with fewer basic colour terms is insightful, because the missing colour terms, by definition, do no co-occur with other words in a language. Speakers must rely on their perceptual experience or imagination of colours. Alternatively, they can substitute a missing basic colour term (e.g., *green*) with a non-basic colour term (e.g., *leaf colour*). In such cases, one could compare speakers who do and do not use the non-basic colour term in their everyday language to learn the importance of a colour term for colour-emotion associations. Even in languages with a larger number of basic colour terms, individuals vary in the number of non-basic colour terms they know and use (Uusküla et al., 2012). A larger colour vocabulary has been related to a better colour memory (Hasantash & Afraz, 2020). Similarly, the size of colour vocabulary and the use of non-basic colour terms in context might shape colour-emotion associations.

6.2.3. Meaning

Colour Preferences

Colour preferences can be defined as “relatively stable evaluative judgments in the sense of liking or disliking a [colour], or preferring it or not over other [colours]” (Scherer, 2005, p. 703). So instead of making (conceptual) associations between two entities, like in colour-emotion associations, people make aesthetics judgments of colours to arrive at colour preferences. Colour preferences have long been explained through hue effects. In an early meta-analysis-like study, Eysenck (1941) compiled data of 21,060 participants from previous studies. He reported that on average blue was ranked the highest and yellow the lowest on a colour preference scale. In other words, participants liked blue hues the most and yellow hues the least. Similar results were also reported in subsequent studies using various measurement techniques, such as rating or ranking pre-selected colours, asking participants to imagine colours, or choosing colours from an unrestricted sample of colours (e.g., Bakker et al., 2013; Dittmar, 2001; Hůla & Flegr, 2016; Jonauskaite et al., 2016; Jonauskaite, Dael, et al., 2019; Ou et al., 2004; Palmer & Schloss, 2010; Schloss et al., 2013; Taylor, Schloss, et al., 2013).

However, hue alone is insufficient in explaining colour preferences and other colour dimensions, namely lightness and saturation, must be considered. Palmer and colleagues (2013) reviewed studies in colour preferences and concluded that, in general, more saturated colours were preferred to less saturated colours while lighter colours were preferred to darker colours. But not all studies found the same associations (e.g., Jonauskaite et al., 2016). In the latter study, preference for lightness and chroma depended on the context for which a colour was chosen. Favourite colours for walls were lighter than least favourite colours while favourite colours for t-shirts were darker than least favourite colours. Favourite colours for t-shirts were also less chromatic than least favourite colours (also see similar findings in Schloss et al., 2013). In conclusion, colour preferences follow a systematic pattern, and all three colour dimensions contribute to preferences. The exact relationship between the colour parameters and preference is modulated by context.

Theories. There are two prominent theories explaining colour preferences. The **cone-opponent contrast theory** of colour preferences relies on perceptual experiences of colours and highlights biological mechanisms of colour preferences (Hurlbert & Ling, 2007, 2012). Hurlbert and Ling suggested that human colour preferences are guided by weights on the two cone-opponent contrast components of the stimuli. The first component is the contrast between the responses of S-cones coding for bluish colours versus L- and M-cones combined coding for yellowish colours (S-(L+M) contrast). The second component is the contrast between the response of L-cones coding for reddish colours versus M-cones coding for greenish colours (L-M contrast). Cone contrasts are neuronal mechanisms, fundamental for the initial colour processing in the eye.

Using the cone-opponent contrast framework, Hurlbert & Ling (2007) explained that most adults have a negative weight on the blue-yellow contrast, preferring blue to yellow. Furthermore, red-green contrasts showed sex differences with adult males preferring green to red while adult females preferring red to green. Together, these components accounted for 70% of the variance in their data (but only 37% or 22% in different populations and different sets of colours, (Palmer & Schloss, 2010; Taylor & Franklin, 2012). Originally, this theory considered only differences in hues while disregarding differences in saturation and lightness (Hurlbert & Ling, 2007). Considering that colour preferences differ for the same hues of different lightness and saturation levels, the theory has been extended to model lightness and saturation as well as cone-opponent contrasts (Ling & Hurlbert, 2007). The updated equation explained 46-61% of variance depending on the colour set.

The **Ecological Valence Theory** (EVT) goes beyond biological mechanisms and highlights the importance of ecological experiences to human colour preferences (Palmer & Schloss, 2010; Schloss & Palmer, 2017). The EVT posits that human colour preferences are driven by valence of objects of the same colour. Positively evaluated objects drive liking of the same colour while negatively evaluated objects drive disliking of the same colour. Accordingly, blue colours are liked because they remind of clear sky and clean water while yellow-brownish colours are disliked because they remind of rotten food, faeces, and other unpleasant matter. Such colour-object associations would be common in most people and therefore largely universal.

The EVT further allows for individual and cultural variations in colour preferences. Individual differences can be explained through at least three mechanisms (see, Schloss & Palmer, 2017).

The first mechanism entails differential experience with objects of the same colour. That is, different people might evaluate the same object differently. The second mechanism entails differences in the objects which are associated with the same colour. That is, different people might think of different objects when thinking about the same colour. The third mechanism entails differences in the degree to which certain objects are "activated" in one's mind. For example, some people might think about "strawberries" more readily when evaluating their preference for "red" than other people.

Currently, the EVT is undoubtedly the most elaborated theoretical model of colour preferences. The EVT has received a great deal of empirical verification (e.g., Schloss et al., 2011, 2015; Schloss & Heck, 2017; Schloss & Palmer, 2014; Strauss et al., 2013; Taylor & Franklin, 2012). In the original study conducted in the USA, the EVT accounted for 80% of variance in colour preferences and outperformed the extended cone-opponent contrast theory. However, the EVT was less successful in accounting for as much variance in other samples outside the USA. In China, the same design accounted for 39% of variance (Palmer, Schloss, et al., 2015) and in Japan for 37% (Yokosawa et al., 2016). In both countries, unlike the USA, the symbolic meaning of colour was very important in explaining colour preferences. The EVT was least successful in the non-industrialised Himba society in Namibia, where it account for only 23% of variance but the relationship was negative (Taylor, Clifford, et al., 2013). This relationship only existed for Himba males while the EVT did not explain any variance in Himba female colour preferences. Unexpectedly and against predictions, Himba males liked colours that were associated with negative objects and disliked colours that were associated with positive objects. Hence, despite being an advanced and empirically validated theory in industrialised societies, the EVT leaves room for further theoretical additions that could account for additional unexplained variance in colour preferences.

Cross-Modal Correspondences Involving Colour

Cross-modal associations with colours are associations with other visual phenomena or other sensory domains, such as sound, touch, taste, emotion, etc. In a way, colour-emotion associations could also be seen as a type of cross-modal associations, or cross-modal correspondences (C. Spence, 2011), especially if emotions are felt rather than conceptually processed. Usually, cross-modal associations are conscious and abstract, and they function as knowledge and can be retrieved on demand. In extreme cases, however, cross-modal associations can arise automatically and involuntary. Such cases are known as **synaesthesia**, and was first reported in 1812 by Georg Sachs, and later by John Locke and Sir Francis Galton (Jewanski et al., 2009).

Synaesthesia. Synaesthesia is a hereditary and very rare condition, occurring to 0.2 – 2.2% of the population (Baron-Cohen et al., 1996; Ward, 2013), although recent studies are showing an even higher prevalence rate (Simner et al., 2006b). When someone has synaesthesia, "one attribute of a stimulus (e.g., its sound, shape, or meaning) may inevitably lead to the conscious experience of an additional attribute. For example, the word "Phillip" may taste of sour oranges, the letter A may be luminous red, and a C# note on the violin may be a brown fuzzy line extending from left to right in the lower left part of space" (Ward, 2013, p. 50). These synaesthetic associations are a genuine phenomenon and are supported by interconnected neural networks. These associations cannot be simply reduced to associative or metaphorical thinking, or vivid imagination (Ward, 2013). Synaesthetic experiences may or may not involve mixing of senses and may or may not involve colours.

One of the most researched type of synaesthesia that involves colours is **colour-grapheme synaesthesia**, where letters or digits are perceived in distinct colours (Baron-Cohen et al., 1987). These colours can either "superimpose" visually perceived letters (i.e., synaesthetes projectors) or be simply perceived in the "eye of the mind" (i.e., synaesthetes associators; (Dixon et al., 2004; R. Skelton et al., 2009). Even a colour-blind person can have this type of synaesthesia (Mckenney et al., 2007). Other types of synaesthetic experiences have been reported for coloured i) days of the week or months (Simner et al., 2006a), ii) musical tones (Ione & Tyler, 2004) [29], iii) proper names (Riggs & Karwoski, 1934; Weiss et al., 2001), and iv) smells (Bleuler & Lehmann, 1881).

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[29] famously possessed by V. Kandinsky (Ione & Tyler, 2004) and M. K. Čiurlonis (Jastrumskytė, 2007), a Lithuanian painter and composer

Moreover, a rare case of **colour-emotion synaesthesia** has been described, where words of an emotional significance, such as names of close people, evoked a perception of a particular colour (Ward, 2004). For the synaesthete GW, “James” was pink, “Hannah” – blue, and “Thomas” – black while unknown names evoked no particular colours. Other words with emotional connotations also evoked colours, which were systematically linked to valence. Positively-valenced words evoked synaesthetic associations with *pink*, *orange*, *yellow*, and *green*, whereas negatively-valenced words evoked associations with *brown*, *grey*, and *black*. *Blue* tended to be associated with neutral words, while *white* was not associated with anything. The synaesthetic colour-emotion associations of GW are strikingly similar with non-synaesthetic colour-emotion associations, discussed in great detail throughout this thesis. Whether or not synaesthetic and non-synaesthetic colour-emotion associations are guided by the same mechanisms are to be seen (see a discussion of other affect-related types of synaesthesia in Dael et al., 2013).

Non-Synaesthetic Cross-Modal Correspondences. Even without synaesthesia, most people have diverse cross-modal correspondences with colours. Cross-modal correspondences can be defined as “tendencies to match sensory features or dimensions across sensory modalities, which are observed in many individuals, but does not mean that the presentation of one sensory feature necessarily gives rise to the conscious experience of the second matching feature”, as in the case of synaesthesia (Deroy & Spence, 2013, p. 646). The correspondences with colours can occur within the same sensory domain (i.e., vision) or across sensory modalities.

Within the visual domain, there are systematic non-random correspondences between shapes and colours. However, which shapes are matched to which colours remains questionable. Cross-modal correspondences outside the visual domain include correspondences between colours and felt emotions, colours and sounds, colours and music, colours and odours, colours and flavours, and potentially others. See Supplemental Material for a more detailed description of non-synaesthetic cross-modal correspondences with colour (Cross-Modal Correspondences with Colour).

Theories. One theoretical framework explains cross-modal correspondences are being a type of **weak synaesthesia** (Martino & Marks, 2001). That is, they argue that everyone is more or less strongly synaesthetic; in other words, are positioned somewhere on a continuum of synaesthesia (Martino & Marks, 2001). Colour-emotion associations have also been sometimes presented as types of synaesthetic associations (Hupka et al., 1997). If true, cross-modal correspondences should be supported by additional neural connections between the areas processing different sensory stimuli. However, others maintain that the two types of correspondences are different and should not be equated (see, Deroy & Spence, 2013; C. Spence, 2011) for an in-depth discussion). For instance, synaesthetic correspondences are much more consistent than non-synaesthetic correspondences (i.e., test-retest reliability of 80-100% vs. 30-50%, respectively; Mattingley et al., 2001). Even after extensive training of tens of thousands of trials, non-synaesthetes do not create synaesthetic experiences (Howells, 1944). Thus, other mechanisms are more likely to be important for non-synaesthetic cross-modal correspondences.

Cross-modal correspondences could be explained in terms of **Bayesian integration theory** (Ernst & Bülthoff, 2004). Using this theory, C. Spence (2011) argued that people "combine stimuli in a statistically optimal manner by combining prior knowledge and sensory information and weighting each of them by their relative reliabilities" (p. 984). The more likely two stimuli are to occur together, the stronger cross-modal correspondence. Furthermore, cross-modal correspondences can be divided into three classes: structural, statistical, and semantic. **Structural correspondences** are supported by neural connections between two sensory modalities (e.g., loudness and brightness). **Statistical correspondences** are supported by an adaptive response of our brains to extract statistical regularities between stimuli naturally co-occurring in our environments (e.g., loudness and size). Finally, **semantically mediated correspondences** arise when common linguistic stimuli are used to describe different stimuli (pitch-spatial frequency).

According to C. Spence (2011), statistical correspondences are more likely to be universal than semantically mediated correspondences since the former are determined by physics and the latter by culture. However, it is not clear if a single mechanism or a combination of mechanisms support each cross-modal correspondence. Also, the theory does not provide clear indications on how to identify the mechanisms for a cross-modal correspondence of interest. When thinking about colour-emotion associations, one could argue in favour of them being statistical and semantically mediated correspondences. More neuroimaging evidence would be necessary to support the possibility of them being structural correspondences too.

Colour Symbolism

Colour terms carry diverse symbolic meanings (see Table 6.2 and a longer explanation in Supplemental Material). However, these symbolic meanings are often inconsistent with one another. For instance, green carries meanings of *freshness* and *youth* but also of *degradation*. Often, colour symbolism is not studied experimentally but rather compiled in historical and linguistic sources (see, Evarts, 1919), If done with scrutiny, such an approach can identify all, or nearly all, possible symbolic meanings. Yet, such an approach cannot reveal how predominant the meanings are, or which of them are context-bound. Without this information, one cannot predict the likelihood that symbolic colour meanings would influence other colour connotations. Furthermore, symbolic colour meanings are likely to differ across cultures and periods of time. Thus, they must be compiled for each cultural group and period separately.

Table 6.2. Symbolic colour connotations extracted from Evarts (1919).

These connotations have been compiled mainly for English speakers, although Evarts (1919) provided an overview of other cultures too.

Colour	Symbolic meaning
Red	Heat, passion, destruction, love, fire, hate, anger, cruelty, sin, fertility, feminism
Orange	Wedding, hope for lasting marriage, adultery
Yellow	Sun, light, warmth, mature harvest, nutrition, creativity, luminosity, cheerfulness, sublimation, human goodness, constancy, degradation, sickness, sin (especially, adultery, theft), deceit.
Green	Freshness, youth, growth, regeneration, activity, charity, hope, defeat, flight, degradation, folly
Blue	Divinity, heavens, sky, death, sadness, sin, serenity, coldness, contemplation, melancholy, aristocracy, truth, honour, fidelity, constancy, serenity, wisdom
Purple	Truth, love, passion, sovereignty, royalty, wrong, evil, falseness, mourning (especially, among royalty)
Pink	Love, royalty (symbolic meanings of *red*, *white*, or *purple*)
Brown	Dead vegetation, decay, death, degradation, distrust, deceit, sadness, strength, vigour, solidity
White	God, light, purity, innocence, chastity, modesty, sickness, death
Grey	May approach the meanings of *black* or *white*, depending on its lightness, or be neutral in symbolism.
Black	Personified evil, death, rebirth, regeneration of a soul, night, beauty, repose.

Feedback Loop Within the Meaning Component

Obvious from the reviewed literature, colours carry diverse associations above and beyond their associations with emotions. Affective experiences, within the framework of the emotion-mediation hypothesis (Palmer, Schloss, Xu, et al., 2013; C. Spence, 2020a), have been crucial when explaining colour preferences (Palmer & Schloss, 2010; Schloss & Palmer, 2017), colour-music (Palmer, Schloss, Xu, et al., 2013; Whiteford et al., 2018), and colour-fragrance (Kim, 2013) correspondences. Thus, one could hypothesise that affective colour meaning, and colour-emotion associations might be a pre-cursor of the cross-modal correspondences with colour.

On the other hand, previous literature has suggested that many of these associations are semantically mediated and abstract (de Valk et al., 2017; Kaeppler, 2018; Saysani, 2019; Shankar et al., 2010). My work also pointed to the direction that colour-emotion associations are abstract. Therefore, it is possible that all the associations interact with each other on a conceptual rather than affective level. The exact interactions are to be determined empirically in the future.

Preferences. Preferences might be a different case within the Colour Meaning component. One has preferences for colours, but also for sounds, music, odours, flavours, and so on. It is possible that preferences for one domain influence preferences for another domain. For instance, liking a particular colour (e.g., *red*) might lead to highlighting more positive associations with this colour (e.g., *love*) while disliking the same colour, might lead to highlighting more negative associations with it (e.g., *anger*).

The importance of preferences has been shown for colour-odour associations. Participants associated colours they liked or disliked with odours they liked or disliked, respectively (Schifferstein & Tanudjaja, 2004). Congruent colours, in terms of their correspondences with odours, also received higher scores of liking and of positive emotions in a different study (Porcherot et al., 2013). Yet, preferences are less important for colour-music associations. Participants did not choose colours they liked/disliked for musical pieces they liked/disliked (Whiteford et al., 2018). Rather, they chose colours for the musical pieces in correspondence with emotions evoked by these musical pieces. Colour preferences and colour-music correspondences do not seem to go hand in hand.

Similarly, colour-emotion associations and colour preferences should not be equated either. While preferences and emotion associations, in terms of valence, seem similar for some colours, they are different for others. Preferences and emotion associations have similar valence for *blue* and *brown*. *Blue* is a liked colour (Eysenck, 1941; Hurlbert & Ling, 2007; Jonauskaite et al., 2016; Palmer & Schloss, 2010) carrying many positive associations (see Table 1.3, Table 1.4 and Chapter 2). *Brown* is a disliked colour (Jonauskaite et al., 2016; Palmer, Schloss, & Sammartino, 2013; Palmer & Schloss, 2010) carrying many negative associations, such as an association with *disgust* (see Table 1.3, Table 1.4 and Chapter 2). Preferences and emotion associations have different valence for *yellow*, *black,* and *pink*. *Yellow* is a very positive colour, associated with *joy* and *amusement* in many countries (see Table 1.3, Table 1.4 and Chapters 2 & 4). Yet, *yellow* has consistently been named as one of the least liked colours (Eysenck, 1941; Hurlbert & Ling, 2007; Jonauskaite et al., 2016; Palmer & Schloss, 2010; Schloss & Heck, 2017; Taylor, Schloss, et al., 2013; Taylor & Franklin, 2012). *Black* is a very negative colour, associated with *sadness*, *fear*, and *hate* across the world (see Table 1.3, Table 1.4 and Chapter 2). Yet, *black* is a relatively liked colour (Jonauskaite, Müller, et al., submitted; Silver & Ferrante, 1995), or at least it is not listed among the least favourite colours (Jonauskaite et al., 2016). Similarly, even though *pink* is one of the most positive colours (see Table 1.3, Table 1.4 and Chapter 2), many people of both genders name it as their least favourite colour (Jonauskaite, Dael, et al., 2019). These examples imply that different cognitive processes underlie preference judgments and associations with emotion concepts.

Colour preferences might also be more personal than colour-emotion associations. Previous studies and the current thesis have reported universally shared colour-emotion associations (Adams & Osgood, 1973; Gao et al., 2007; Jonauskaite, Abu-Akel, et al., 2020; Ou et al., 2018). In contrast, colour preferences are less shared, especially when non-Western participants are taken into account (Davis et al., 2021; Groyecka et al., 2019; Taylor, Clifford, et al., 2013). There are also more individual differences in colour preferences, and these differences can be accout by different weights put on colour-object associations (Schloss & Palmer, 2017).

To sum up, colour preferences, measured as *liking* or *disliking* of a colour, are different from colour-emotion associations, even when measured as the degree of *positivity* or *negativity* of a colour. Other authors (Itkes & Kron, 2019) maintain a further separation of valence, namely, that **semantic valence** (i.e., how good or bad something is) is different from **affective valence** (i.e., how pleasant or unpleasant something is). How preferences relate to semantic and affective types of valence is a question for future research. Likewise, future research is necessary to demonstrate which cross-modal colour correspondences and which affective colour associations drive human behaviour in real-life settings.

6.2.4. Behaviour

Affective Changes

In Western societies, we are regularly informed about best ways to enhance our affective states, improve well-being and avoid negative health outcomes (for a review, see O'Connor, 2011). One of these ways is colour therapy, or chromotherapy, where colours are believed to have unique psychological effects. For instance, red is believed to excite and activate, blue to calm and relax, green to offer equilibrium, yellow to uplift (Scott-Kemmis, 2018a). These ideas can be traced back to the early colour theorists, who cited anecdotal evidence how colours can affect bodily states. Luscher (1969, cited in O'Connor, 2011, p. 232) claimed that "red has a stimulating effect on the nervous system, blood pressure increases, respiration rate and heartbeat both speed up; while blue has the reverse effect, blood pressure falls, heartbeat and breathing both slow down". The proposed physical, biological, and cognitive mechanisms, underlying colour influence on affective states should be empirically validated. At present, however, empirical evidence for such beneficial effects is weak.

In favour of this supposition is the belief that a specific shade of pink (so-called *Baker-Miller pink*) reduces aggressiveness in prisoners by diminishing their physical strength (Pellegrini et al., 1981; Schauss, 1979). It was assumed that the visual processing of the *Baker-Miller pink* "influences" neurological and endocrine systems causing reduced physical strength, and consequently aggressive behaviour. A recent publication, however, did not replicate the relationship between pink cells and reduced aggression in their inmate population (Genschow et al., 2015). In the latter study, aggressiveness simply diminished with the passage of time, irrespective of whether prisoners were held in pink or white cells [30]. Despite inconsistent findings, many prisons in Europe and the United States have at least one pink prison cell (see counts of pink cells in (Genschow et al., 2015), showing that the public is eager to apply colour-related advice.

Other studies further investigated the effect of colours on human affective states. Von Castell and colleagues (2018) empirically tested three commercially available colours and their allegedly favourable effects. They assessed whether *Cool Down Pink* produced relaxing effects and reduced effort; *Energy Red* enhanced performance via increased arousal; and *Relaxing Blue* improved attention and concentration. None of these colours changed affective states of their participants. In a another study, carried out in virtual reality (VR), participants rated their affective states after exposure to differently coloured walls (Lipson-Smith et al., 2020). Some of these rooms were plain (i.e., just bare walls) while other rooms simulated real environments, such as a healthcare waiting room or a living room. Exposure to pink decreased a positive mood, which went to the opposite direction than expected for the Baker-Miller pink. Exposure to various shades of blue increased positive mood, but only when participants rated bare walls and not more realistic rooms. The latter finding questions the applicability of blue in real-life settings. Indeed, different colours of living spaces in dormitory rooms did not affect participants' mood over the course of weeks in a real-life study (Costa et al., 2018).

Perceptual Changes

Although it is theoretically possible that current affective states influence colour perception, very few studies tested such effects and even fewer reported significant findings. Bubl et al. (2010) compared objectively measured contrast sensitivity at a retinal level between patients with major depressive disorder (MDD) and control participants. They hypothesised that

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[30] Many factors could account for the discrepant findings. Perhaps, different prisoner populations were assessed in these studies, perhaps prisons in the USA differ from prisons in Switzerland, or perhaps, prisons have changed over the last 40 years.

depression leads to seeing the world more "greyish" and indeed reported that MDD impaired contrast sensitivity. Just from this measure, the authors could accurately separate people with and without MDD (also see, Fitzgerald, 2013). Another study attempted to extend the observation into a non-clinical population. Thorstenson and colleagues (2015) induced happy, neutral, or sad moods with video clips and measured participants' colour recognition. They reported that participants in the sad mood condition had impaired recognition along the yellow-blue axis. Unfortunately, the study suffered from numerous methodological and statistical drawbacks (Holcombe et al., 2016) and thus was quickly retracted from the journal. Therefore, this study does not provide convincing evidence that affective states change colour perception in the general population. Finally, a recent study tried to link the size of colour vocabulary with memory for colours and colour perception (Hasantash & Afraz, 2020). While participants with richer colour vocabulary remembered colours more accurately, they were not better in a perceptual colour matching task. The authors concluded that variation in colour naming or memory was unrelated to low-level colour perception. Taken together, current literature shows barely any evidence that colour perception is impacted by colour meaning or affective experiences.

Cognitive Changes

Elliot (2015) and Elliot and Maier (2014) reviewed the existing literature regarding the psychological consequences of colour and compiled a list of potential effects. The list included effects of colour on selective attention, alertness, athletic performance, intellectual performance, aggressiveness or dominance evaluation, avoidance motivation, attraction, store or company evaluation, and eating and drinking. In most cases, the colour *red* played the major role. For instance, in a series of studies, Elliot and colleagues (2007) assessed whether red, which is associated with danger, would impede intellectual performance. Indeed, participants who saw their participant number written in red as compared to green or black performed worse on an IQ test – they solved fewer anagrams in a given time (also see, Mehta & Zhu, 2009). In another study (Gnambs et al., 2010), a red versus green progress bars impeded performance on a general knowledge test, but only for men. However, many other studies failed to replicate these and similar effects completely (Gnambs et al., 2020; Steele, 2014; Wolf & Schütz, 2019). For instance, Larsson and Von Stumm (2015) reported no difference in the test scores between red and green participant number conditions, questioning whether red impedes intellectual performance only for some tasks and not intelligence in general. Overall, evidence for colour effects on behaviour and cognition remains inconclusive and weak.

Decisions and Judgments

Colour can act as a signal and influence one's decisions. These effects have been intensively studied within the framework of marketing and consumer research studies. Without going into an extensive review, which can be found elsewhere (Aslam, 2006; Labrecque & Milne, 2012), several findings stand out. For instance, blue is a very popular choice for company logos, especially tech/IT companies (e.g., IBM, HP, Intel, R Studio, SPSS) and social media (e.g., Facebook, Twitter, Skype; Labrecque & Milne, 2013) and for a good reason. Research shows that blue shops or websites are rated as more relaxing, less crowded, more competent, and more trustworthy (Alberts & van der Geest, 2011; Labrecque & Milne, 2012). In contrast, red logos are rated as more exciting, and black as more sophisticated (Labrecque & Milne, 2012). Some of these brand "personality" evaluations are positively related to purchase intent (e.g., sophistication and ruggedness). Prices presented in red font seem like a "better deal" than the same prices presented in black (but only for men, Su et al., 2019). However, product colour should not be taken out of context, as an intention to buy is influenced by an interaction between a product colour and an environmental colour (Martinez et al., 2021). These and similar effects are likely influenced by Colour Meaning, may it be cross-modal correspondences or associations with emotions. The exact mechanisms via which colour affects behaviour are not yet clear, especially considering a multitude of diverse findings in the marketing studies.

Influence of the Meaning Sub-Components on Behaviour

So far, researchers have not focused on how different colour connotations relate to behaviour. Let's take *black* as an example. Black is nearly exclusively associated with negative emotions. Preference for black is varied – some like it more and others less. And yet, black is a common choice for everyday clothing, which seems to indicate that negative emotional associations have little impact on this choice. If not colour-emotion associations, what else could explain this choice? The *little black dress* has become synonymous with elegance. Black is also associated with sophistication and luxury brands (Labrecque & Milne, 2012), and is believed to make one look thinner. The latter more positive connotations might be driving one's choice to dress in black despite the co-existing negative meanings.

In other cases, colour preferences might over-run colour-emotion associations. We know that shades of favourite colours are highly varied (Jonauskaite et al., 2016) and that people often choose products in their favourite colours, especially if a product colour has no practical significance (Jiang et al., 2020; Westland & Shin, 2015; Yu et al., 2018). Thus, individual colour preferences rather than shared colour-emotion associations are more likely to explain purchase decisions. Furthermore, let us consider the result that exposure to *pink* decreased positive emotions experimentally (Lipson-Smith et al., 2020). Again, preferences might be more important for such affective experiences than associations with emotions. If one does not like pink, then being emerged in this colour for a period of time might decrease one's mood irrespective of having positive emotional associations with *love* and *amusement*. Future studies are needed to understand which colour connotations are driving behaviours and consequences and how their influences manifest.

6.3. Strengths, Challenges, and Future Directions

In the last section of the thesis Discussion, I am considering the strengths of the current studies, challenges that have arisen and open questions for future studies. Some challenges were common to most cross-cultural studies and others were more specific to the current studies. Many future directions were mentioned when discussing the Colour Connotation Theory. Here, I expanded on a few additional and most compelling future avenues.

6.3.1. Strengths of the Current Studies

Throughout the empirical studies of this thesis (Chapters 2-5), we used identical methodologies to obtain consistent and easily comparable results. In all four chapters, we tested associations between emotion concepts and colour terms, always using the exact same set of emotion and colour terms, and in native languages. We translated the survey into 46 languages to avoid potential influences of the use of a non-native language (e.g., Caldwell-Harris, 2015; Colbeck & Bowers, 2012; Freeman et al., 2016; Pavlenko, 2012). We believe that emotion and colour term sets were sufficiently large to detect systematic colour-emotion associations.

The set of emotion terms included a theoretically motivated selection of emotion terms, derived from natural languages, and varying across the three affective dimensions (valence, arousal, and power; Scherer et al., 2013). The set of colour terms included all basic colour terms and provided an exhaustive list of colour terms, which can be used to categorise all perceptual colours into categories, known by almost all speakers of the same language. Colour and emotion terms were presented in participants' native language to ensure maximal understanding of these terms.

In Chapters 3 and 5, we additionally assessed emotion associations with colour patches, again identical in both studies. Colour patches represented focal colours of the colour categories, assessed via the colour terms, making a comparison between terms and patches straightforward. Even though the focal colours were originally selected from a study with native American English participants (Lindsey & Brown, 2014), these colours were easily identified by Swiss French-speaking participants, with and without colour blindness.

Furthermore, we did not restrict the number of emotion associations with each colour. By allowing many-to-many rather than one-to-one associations, we ensured we captured the entire breadth of colour-emotion associations. While more associations could be captured by adding non-basic colour terms and non-focal colour patches (see below), we believe we recorded all existing associations within the given set of colour and emotion terms. Evidently from Figure 2.3, Figure 3.2, and Figure 5.2, some emotions did not have many associations with colours (i.e., *compassion* and *contempt*). If needed to restrict the sample of colours and emotions, these emotions could be eliminated in future studies.

6.3.2. Challenges and Future Directions

Basic Colour Terms and Focal Colours

Throughout the thesis, emotion associations were gathered for basic colour terms and/or focal colours. Both, basic colour terms and focal colours are overlearned, evident from the fact that colour blind participants had no trouble identifying them (Chapter 5; also see Álvaro et al., 2015; Moreira et al., 2014; Saysani et al., 2018b). By using focal colours, we were not able to disentangle the contribution of hue, saturation, and lightness components to emotion associations. We almost exclusively focused on hue and the corresponding colour categories. This design might have guided participants towards conceptual associations and under-estimated the importance of perceptual experience. Previous studies have shown important associations between lightness and chroma with emotions (see Table 1.3).

Likely, emotion associations with **non-basic colour terms** or with **non-focal colours** would be more varied across individuals and cultures. When studying non-basic colour terms, cultural associations might be more important role as the terms are not universal themselves (e.g., an *autumn-leaf* colour makes more sense in countries with four seasons). When studying non-focal colours, colour perception might become more significant for colour-emotion associations. Using colour patches that are difficult to name could separate the learned component from the experiential component of colour-emotion associations. For instance, one could examine if a shade of colour bordering *green* and *brown* would receive emotion associations consistent with the identified colour category (i.e., *green* or *brown*) or consistent with the perceptual experience of hue, saturation, and lightness of this colour patch. Non-focal colour patches are particularly interesting for colour-blind participants. The latter not only see these patches differently but are also likely to categorise them differently than trichromatic participants. Based on the naming data, the perceptual versus the linguistic component could be separated.

Individual Differences

In empirical Chapters 2, 3, and 5, we analysed participants on a **group level**. By doing so, we inevitably ignored potential individual differences. For instance, in Chapter 2, we reported universality in the patterns of colour-emotion associations, which meant that a similar proportion of participants chose a specific colour-emotion association in every nation. This result did not mean that *everyone* agreed on which colours and emotions were associated together. In fact, the agreement across 30 nations was rarely over 50%.

If we take *red* as an example, it was most frequently associated with *love* and *anger.* However, these emotions were respectively chosen only by 66% and 48% of all participants. We do not know if the same of different individuals chose *love* and *anger* for *red*. Especially where agreement fell below 50%, it was possible that some participants endorsed only the positive and others only the negative affective side of *red*. This inclination towards the positive or the negative side was evident across nations: for instance, more Lithuanians choose *love* (79%) than *anger* (41%), while more Americans choose *anger* (81%) than *love* (55%) for *red*. One might notice that agreement between individuals was somewhat larger within a nation than globally across 30 nations. An agreement on an association within a nation sometimes reached nearly 80% (e.g., Lithuania, New Zealand, Finland), suggesting few individual differences for some colour-emotion associations.

Different socio-demographic or linguistic factors could potentially explain this variability. In this thesis, linguistic and geographic closeness increased closeness in colour-emotion associations (Chapters 2 and 4). Men and women had strikingly similar patterns of associations (r = .987), suggesting few gender differences existed in colour-emotion associations (Chapter 2). Similarity across adults of different ages was also very high ($r \geq .96$), suggesting few age-related differences, at least in adulthood. Nonetheless, we noticed that colour-emotion associations pattern similarity followed an inverted U-shape (Chapter 2). Somewhat lower pattern similarities were observed in the youngest (under 20 years old; r = .96) and the oldest (over 70 years old, r = .90) participants and the highest similarities were among young and middle-age adult participants (20-60 years old; *r's* = [.98=.99]). Even lower pattern similarities were observed for 9-13-year-old children, when compared to young adults in another study (r = .73, (Müller, 2020). Thus, there might be important developmental and age-related changes in colour-emotion associations. These variables could be applied on an individual rather than a group level to understand why only some participants endorse certain colour-emotion associations.

In fact, colour-emotion associations were measured at a single time point so intra-individual differences were completely ignored. One must assess colour-emotion associations **longitudinally** to learn if these associations change over time and during development. A longitudinal study of colour preferences indicated that such changes exist for colour preferences. Autumn-like colours were preferred to a greater extent as there were more of these colours in the environment (Schloss & Heck, 2017). Likely, some modulations happen for colour-emotion associations too, although they were not detected for *yellow-joy* associations, when compared across seasons (Chapter 4).

Cross-Cultural Studies

Norenzayan and Heine (2005) claimed that cross-cultural studies have “the greatest potential for making compelling cases about universals”. However, the researchers also identified some challenges, which might limit generalisability of the results. The first challenge is a high cost and effort needed to run cross-cultural studies, as researchers tend to cut corners and look for shortcuts to minimise the cost of such work. In particular, researchers tend to study populations that are within their reach – undergraduate psychology students in industrialised countries. If data are entirely collected from undergraduate psychology students, any reported similarities between nations could be due to similar cultural experiences rather than true cross-cultural universality. A more compelling case for universality could be built by testing more diverse populations like non-student samples or individuals from **small-scale societies** (for examples, see Berlin & Kay, 1969; Brown, 1991; Cowen & Keltner, 2017; Henrich et al., 2005; Sauter et al., 2010).

In the current cross-cultural studies (Chapters 2 and 4), we collected data from participants of a wide age range, ranging from 16 to 87 years old. Wide age range ensured that the obtained results were not specific to a particular age cohort and that non-student samples were also included. Furthermore, the survey was translated into 46 local languages and native speakers of these languages completed the survey. Having multiple languages ensured that our population was not limited to English speakers, who constitute a minority of a population in some countries. Despite these efforts, some might argue that the observed universality of colour-emotion associations in fact reflects the existence of a globalized world. This concern might be justified as we tested computer-literate participants who had access to a computer and completed the survey online. To test generalizability of our results, one would need to go beyond the industrialised world and assess colour meaning in small-scale societies or places with limited access to popular mass media and mass-produced items (e.g., Davidoff et al., 1999; Davis et al., 2021; Groyecka et al., 2019; Taylor, Clifford, et al., 2013).

The second challenge is **a trade-off between experimental rigour and the number of studied cultures**. As Norenzayan and Heine (2005) highlighted, it is challenging and costly to run multiple laboratory studies in many different cultures at once while maintaining experimental rigour. More commonly, researchers resort to brief questionnaire measures, which suffer from diverse methodological challenges when compared cross-culturally (Heine et al., 2002). In the current studies, we decided to use an online survey to reach a larger number of potential participants. However, when testing colour cognition outside the laboratory, and especially online, it is nearly impossible to accurately control colour presentation. Without being able to calibrate the screens, colour perception might vary from participant to participant and be unreliable and unreproducible. For this reason, we resorted to testing emotion associations with colour terms when testing online (Chapters 2 and 4). In the remaining Chapters 3 and 5, we employed the identical procedure in the laboratory to assess associations with colour terms as well as with colour patches. High correlations between emotion associations with terms and patches in both chapters vouch for stability of colour-emotion associations across media. To evaluate whether online and laboratory studies produced similar results, I further correlated the patterns of emotion associations with colour terms in Chapter 2 and Chapter 5 of non-colour-blind participants coming from Switzerland. The obtained correlation was high (r = .884), further vouching for sufficiently high experimental rigour in the online studies.

Conclusions

In this thesis, I set out to investigate universality and stability of colour-emotion associations. By consistently using the same methodology and testing emotion associations with colour terms and colour patches across many countries and diverse perceptual experiences, I reported consistent colour-emotion associations. More specifically, emotion associations with colour terms were similar among participants coming from 30 nations, leading to the conclusion that colour-emotion associations are universal (Chapter 2). I reported similar emotion associations with basic colour terms and focal colour patches, demonstrating that the mode of colour assessment was irrelevant for these associations to occur (Chapter 3). Nonetheless, perceptual experience somewhat modulated colour-emotion associations, as nations linguistically and geographically closer associated colour terms with emotions more similarly (Chapters 2 and 4). Colour-blind individuals overall associated similar emotions with colour terms or patches, as non-colour-blind individuals but showed a slightly lower patch-term similarity than non-colour-blind individuals (Chapter 5). The latter findings highlight that intact colour vision is not necessary for colour-emotion associations can occur, or at least, conceptual processing is sufficient in adulthood.

These studies led to three conclusions. First, colour-emotion associations are universal across nations, across colour presentation modes, and different perceptual experiences. Second, these associations are further modulated by perceptual and linguistic experiences. Third, colour-emotion associations have a strong conceptual component, suggesting that these associations are abstract rather than driven by direct visual or affective experience. These findings provide a solid baseline knowledge regarding colour-emotion associations, which enabled me to make a theoretical suggestion – the Colour Connotation Theory. The latter links potential mechanisms driving psychological colour meaning and attempts to explain its effects on human behaviour. Future studies interested in colour-emotion associations can explore many interesting avenues, including scrutinising the universality tenet, studying psychological and cognitive mechanisms driving these associations, or understanding stability and changes within the same person and across time. In the long term, this understanding will help bridging a gap between empirical knowledge and practical applications in design, marketing, or health sector.

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Supplemental material

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Chapter 2.

Supplemental Method Details

Translation of the GEW

The English, Dutch, Estonian, Finnish, French, German, Italian, Traditional Mandarin Chinese, and Polish versions of the GEW are available from the Swiss Centre for Affective Sciences (http://www.affective-sciences.org/gew https://www.affective-sciences.org/research/topics/specific-research-projects/language-and-culture/grid-project/emotion-words/). For all other nations, our collaborators and co-authors translated the GEW into their respective national languages (i.e., Arabic, Azerbaijani, Georgian, Greek, Hebrew, Lithuanian, Norwegian, Persian, Russian, Serbian, Simplified Mandarin Chinese, Spanish, Swedish, and Ukrainian; see Table S 3 for the emotion concepts in all languages). To ensure that the meaning of the translated emotion concepts was as close as possible to the meaning of the original emotion concepts, we followed the back-translation technique. Following this technique, one translator (a bilingual person in the target and reference language) translated the emotion concepts into the target language. Then, the second translator (a bilingual person in the target and reference language) translated the emotion concepts from the target to the reference language without knowing the original reference version. Then, the two versions – the reference and the back translated version – were compared, and the discrepancies were resolved through discussion and consultation of dictionaries. Although we cannot guarantee that the original meaning of the emotion terms remained unchanged in the translations (similar concerns were expressed in Adams & Osgood, 1973), all efforts were made to bring the translations as close as possible to the original meaning, and as similar as possible across languages.

Bayesian Probabilities

We constructed Bayesian models with Monte-Carlo Markov Chains (MCMC) to estimate the average probability that participants associated each emotion concept with the given colour term (Lee & Wagenmakers, 2013). The Bayesian method consists of comparing an a-priori distribution of the probabilities of parameter values (without taking into account the data, i.e., the prior distribution) with a posterior distribution (when taking into account the data). The parameter values were 240 colour-emotion associations. Participants' raw responses were recoded as 1 if an emotion was associated with the given colour term (irrespective of emotion intensity), and 0 if an emotion was not associated with the given colour term, and were fitted to a Bernoulli distribution.

We used a uniform prior distribution, which provides a neutral and un-biased starting point, due to the lack of more informative priors in the literature. The uniform distribution assumes that each emotion parameter value (between 0 and 1) is equally probable across all participants for a given colour term. We constructed the posterior distribution using the MCMC method with 10,000 iterations and three chains (thinning interval was 1). We used a JAGS code to generate three MCMC chains, each comprised of 10,000 iterations. After discarding the first 5,000 iterations from each chain burn-in and confirming convergence by visual inspection and the R statistic (Gelman & Rubin, 1992), we collapsed the samples across the three chains so that our inference was based on a total of 30,000 samples from the joint posterior. MCMC is a computer-driven sampling method that efficiently produces samples from a probability distribution that is otherwise difficult to sample from directly (van Ravenzwaaij et al., 2018). Bayesian analyses were implemented in R with the help of "MASS" (Venables & Ripley, 2002) and "rjags" packages.

Multivariate Pattern Classification

Only participants who had provided ratings for all of the 240 colour-emotion associations were included in the analysis (N = 4410). For the classification algorithm, we selected a support vector machines (SVM; Platt, 1998)) with a radial basis function (RBF) kernel, and used error-correcting output codes (ECOC) for the multiclass classification (Dietterich & Bakiri, 1995). To optimize the hyperparameters of the SVM (complexity constant C and the λ-parameter of the RBF kernel), we used Bayesian optimization based on 5-fold cross validation. Because the sample sizes differed between our 30 nations, we used a uniform prior when training and evaluating the classifier, so that the results were not affected by the differing prior probabilities of the 30 classes (i.e., nations). To evaluate the accuracy of the classifier, a ten-fold cross-validation (CV) was conducted. The analyses were implemented in Matlab (function *fitcecoc*). A summary measure of the predictive power of a classifier is the area under the receiver operating characteristic (ROC) curve (AUC). This measure provides information about the degree to which the predicted nation is concordant with the actual nation. Areas of 0.5 and 1.0 correspond to performances at chance level and perfect performance of the classifier, respectively. AUC is not affected by response bias or by prior probabilities of the classes.

We compared the performance of the classifier to the performance of the same method on randomized data sets. The randomized data sets were generated by randomly permuting the class values (i.e., nation labels) of the data set (Good, 2005).

Linguistic Distances

We have included the following languages from Jäger (2018) in our analyses: AZERBAIJANI_NORTH_2, DUTCH, ENGLISH, ESTONIAN, FINNISH, FRENCH, GEORGIAN, GREEK, HEBREW, ITALIAN, LITHUANIAN, MANDARIN, NORWEGIAN_BOKMAAL, PERSIAN, POLISH, RUSSIAN, SERBOCROATIAN, SPANISH, STANDARD_ARABIC, STANDARD_GERMAN, SWEDISH, and UKRAINIAN.

Supplemental Figures

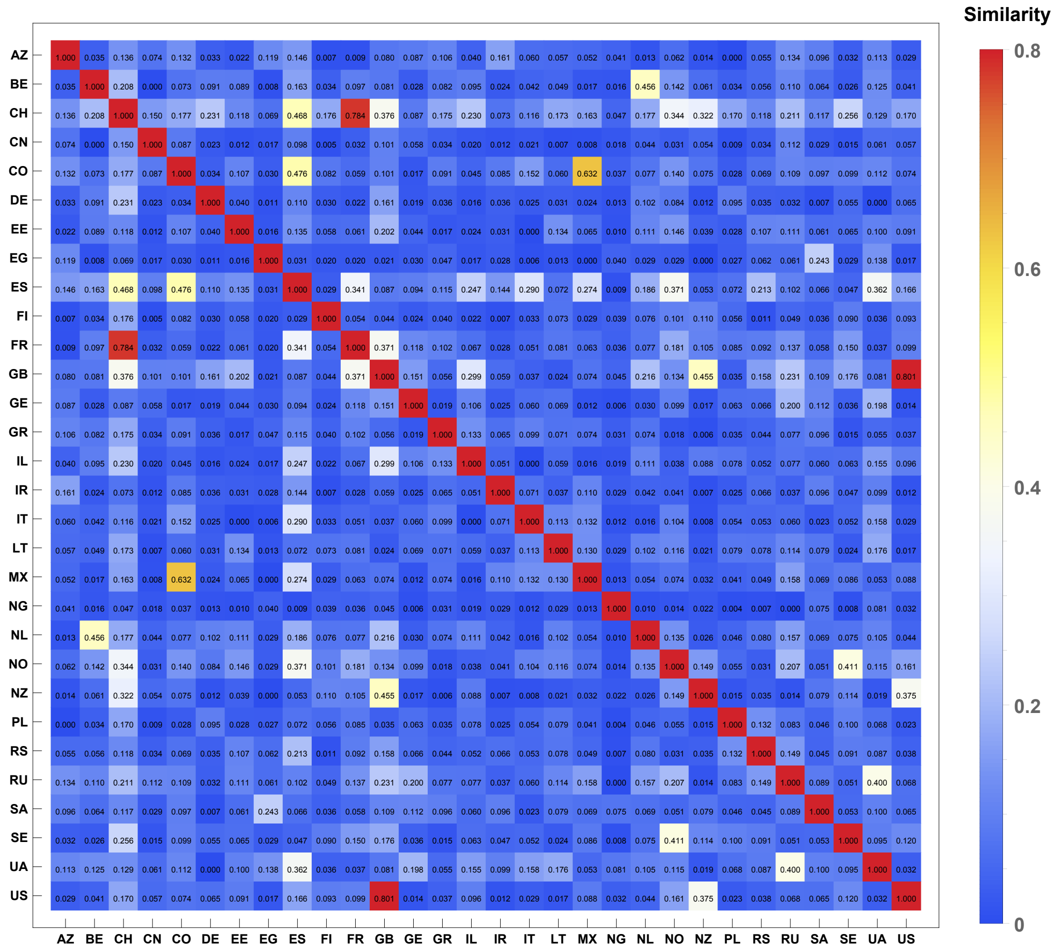

Figure S 1 Estimated similarity between pairs of nations according to Luce's biased choice model applied to the classifier confusion matrix.

Similarity is coded on a temperature scale ranging from blue (0, no similarity) to red (1, perfect similarity). Nation codes are available in Table S 1.

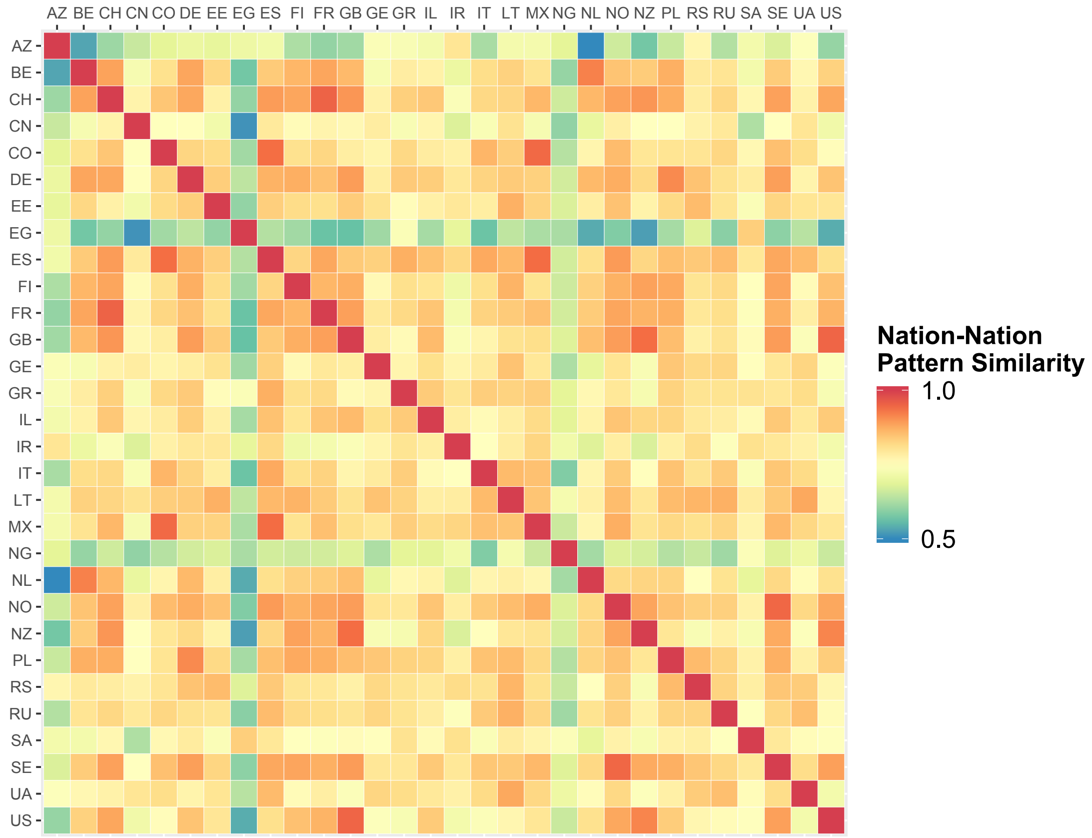

Figure S 2 Nation-to-nation colour-emotion association pattern similarity.

Same data as in Figure 2.4 B. Redder cells indicate higher pattern similarity (correlation). Nation codes are available in Table S 1. Actual correlation coefficients are available in Table S 7.

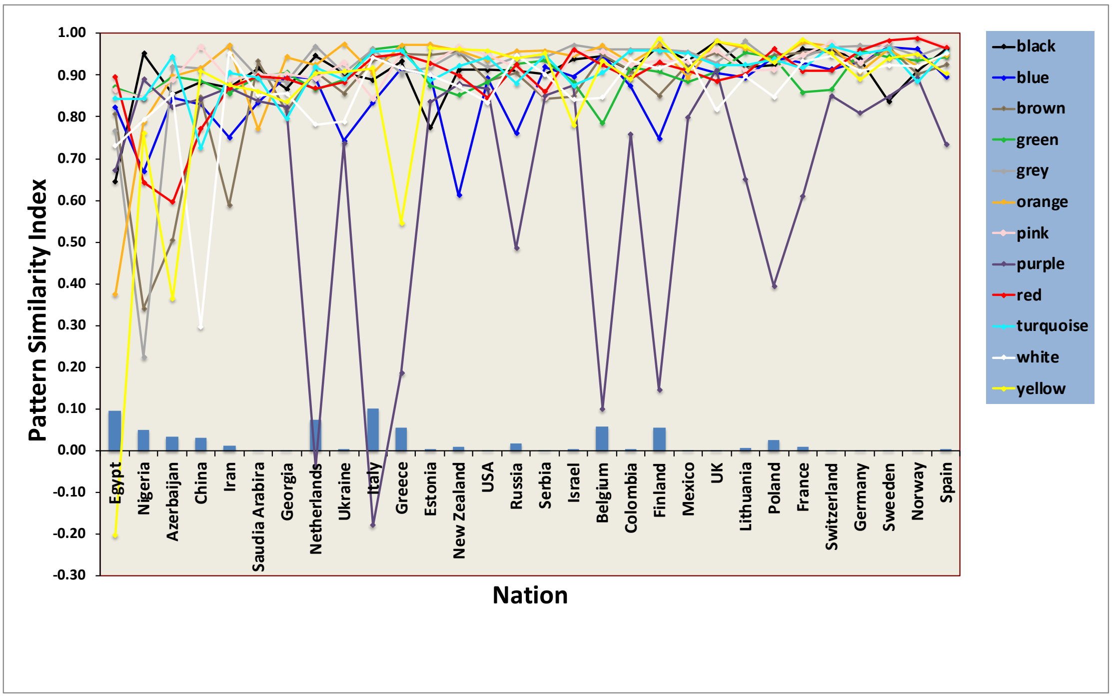

Figure S 3 Colour-emotion association pattern similarities by nation and colour term.

These correlation values indicate the degree of similarity between the pattern of associations of a specific nation to the global association pattern for each colour term (nation-to-global comparisons for each colour term separately). Blue bars represent the variance in the pattern similarities across the colour terms for each nation. Nations have been ordered in the same order as in Figure 2.4 B.

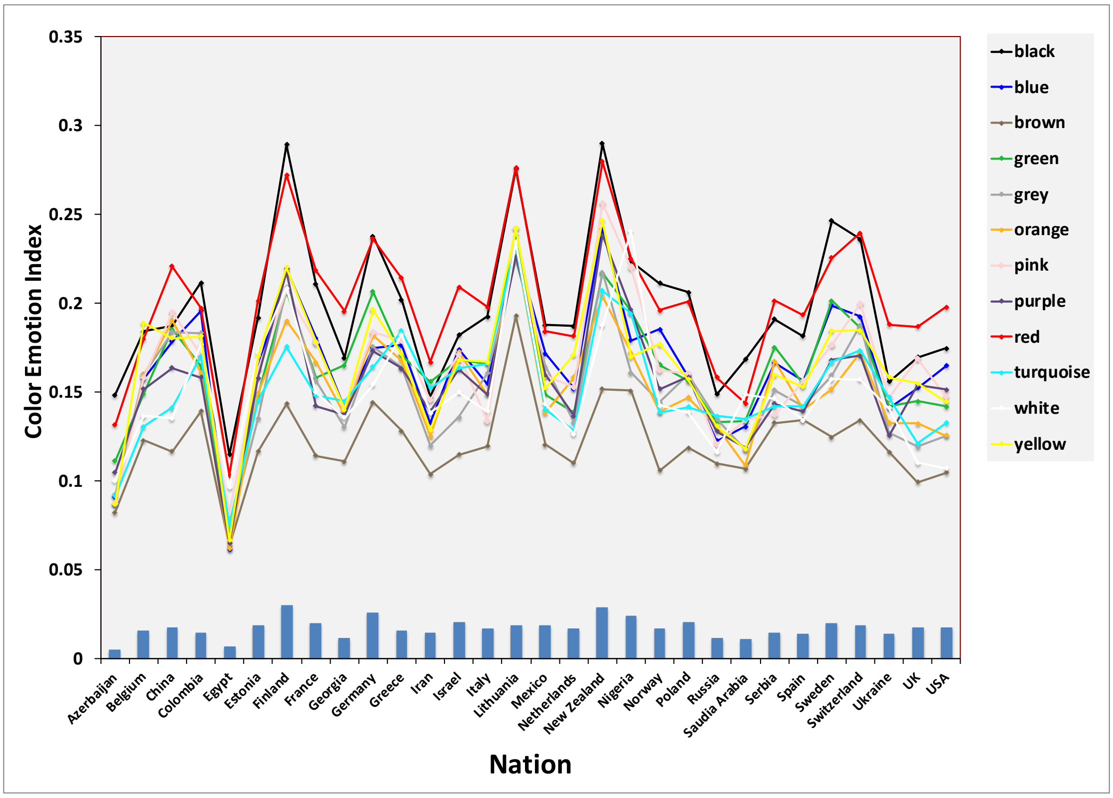

Figure S 4 Average probabilities of colour-emotion associations by nation and colour term.

Higher average probabilities indicate a higher probability that a particular colour term is associated with any emotion among the participants of each nation. Bars represent the variance in the average probability scores across the 12 colour terms of each nation per colour term.

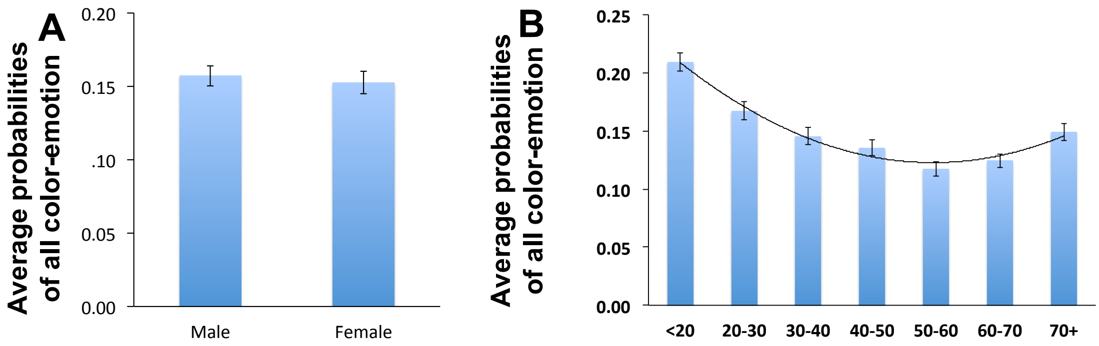

Figure S 5 Average probabilities of all colour-emotion associations by sex (A) and age (B).

Higher numbers indicate a higher average probability that any colour term is associated with any emotion in that particular group of participants. We observed no sex difference. Age followed a U-shaped pattern. Error bars represent standard error of the mean.

Supplemental Tables

See next pages

Table S 1. Language information of the participants by nation.

Country code	Nation (country of origin)	Region	Native language & language of the survey	Language family	Language sub-groups
AZ	Azerbaijan	West & Central Asia	Azerbaijani	Turkic	Oghuz
BE	Belgium	Europe	Dutch	Indo-European	Germanic
CN	China	East Asia	Mandarin Chinese (simplified)	Sino-Tibetan	Chinese
CO	Colombia	South America	Spanish	Indo-European	Romance
EG	Egypt	North Africa	Arabic	Afro-Asiatic	Semitic
EE	Estonia	Europe	Estonian	Uralic	Finnic
FI	Finland	Europe	Finnish	Uralic	Finnic
FR	France	Europe	French	Indo-European	Romance
GE	Georgia	West & Central Asia	Georgian	Kartvelian	Karto-Zan
DE	Germany	Europe	German	Indo-European	Germanic
GR	Greece	Europe	Greek	Indo-European	Hellenic
IR	Iran	West & Central Asia	Persian	Indo-European	Indo-Iranian
IL	Israel	Middle East	Hebrew	Afro-Asiatic	Semitic
IT	Italy	Europe	Italian	Indo-European	Romance
LT	Lithuania	Europe	Lithuanian	Indo-European	Baltic
MX	Mexico	Central America	Spanish	Indo-European	Romance

NL	Netherlands	Europe	Dutch	Indo-European	Germanic
NZ	New Zealand	Zealand	English	Indo-European	Germanic
NG	Nigeria	Africa	Igbo & English	Indo-European	Germanic
NO	Norway	Europe	Norwegian (Bokmål)	Indo-European	Germanic
PL	Poland	Europe	Polish	Indo-European	Slavic
RU	Russia	North Asia	Russian	Indo-European	Slavic
SA	Saudi Arabia	West & Central Asia	Arabic	Afro-Asiatic	Semitic
RS	Serbia	Europe	Serbian	Indo-European	Slavic
ES	Spain	Europe	Spanish	Indo-European	Romance
SE	Sweden	Europe	Swedish	Indo-European	Germanic
CH	Switzerland	Europe	French	Indo-European	Romance
UA	Ukraine	Europe	Ukrainian	Indo-European	Slavic
GB	United Kingdom	Europe	English	Indo-European	Germanic
US	United States	North America	English	Indo-European	Germanic

Table S 2. Demographic information of the participants by nation.

Note, 15 participants did not wish to report their gender and 55 participants did not wish to report their age (missing values).

Nation	Participant count	Youngest	Oldest	Mean age	SD of age	Males	Females	% of males	% of pps for whom color is important in their lives	% of pps for whom color is NOT important in their lives
Azerbaijan	490	17	70	36.22	13.71	128	361	26.12	85.71	9.18
Belgium	88	19	87	38.82	16.68	20	68	22.73	81.82	15.91
China	163	17	80	37.90	19.26	43	119	26.38	77.30	16.56
Colombia	108	15	74	36.16	15.06	51	57	47.22	83.33	13.89
Egypt	209	16	73	30.53	12.45	64	145	30.62	93.30	6.22
Estonia	140	19	70	38.93	11.97	17	123	12.14	76.43	20.00
Finland	140	19	71	32.38	13.94	17	122	12.14	77.86	18.57
France	93	20	71	38.17	15.64	22	70	23.66	86.02	12.90
Georgia	127	16	73	32.73	15.04	36	90	28.35	71.65	25.98
Germany	219	16	82	33.45	15.98	29	189	13.24	83.11	14.16
Greece	275	15	76	30.53	11.50	34	240	12.36	94.18	4.73
Iran	121	16	63	31.49	9.94	14	107	11.57	88.43	6.61
Israel	69	21	67	38.04	11.29	11	58	15.94	60.87	36.23

Italy	108	20	80	38.98	15.50	38	70	35.19	79.63	10.19
Lithuania	124	15	77	36.50	15.97	27	97	21.77	86.29	11.29
Mexico	127	16	78	36.39	15.43	53	74	41.73	85.04	11.02
Netherlands	72	17	71	38.63	15.83	26	46	36.11	73.61	25.00
New Zealand	173	18	73	25.10	10.59	43	129	24.86	79.19	18.50
Nigeria	127	19	65	37.92	12.63	55	72	43.31	66.14	15.75
Norway	211	18	79	34.71	14.09	25	183	11.85	84.36	13.27
Poland	177	17	70	30.72	12.75	40	137	22.60	81.92	15.25
Russia	127	16	78	37.02	16.68	49	78	38.58	47.24	49.61
Saudi Arabia	143	15	85	32.55	13.62	48	94	33.57	86.71	11.89
Serbia	97	19	78	40.85	17.02	24	73	24.74	76.29	21.65
Spain	164	19	75	33.90	13.20	36	127	21.95	81.10	18.29
Sweden	196	20	82	34.63	12.11	35	160	17.86	86.22	13.27
Switzerland	193	18	79	29.35	13.95	47	145	24.35	81.35	18.13
Ukraine	65	18	87	43.37	24.35	8	57	12.31	75.38	21.54
United Kingdom	156	16	71	40.12	13.93	50	106	32.05	84.62	13.46
United States	96	19	75	42.90	14.26	24	70	25.00	87.50	12.50
Global average	4598	15	87	34.81	14.74	1114	3467	24.23	81.65	15.13

Table S 3. Emotion terms in all the languages used in this study (divided into three tables).

English	Arabic	Azerbaijani	Chinese (Mandarin)	Dutch	Estonian	Finnish	French
Interest	اهتمام	Maraq	感兴趣	Interesse	Huvi	Kiinnostus	Intérêt
Amusement	تسلية	Əyləncə	欢愉	Amusement	Iõbu	Huvittuneisuus	Amusement
Pride	كبرياء	Qürur	自豪	Trots	Uhkus	Ylpeys	Fierté
Joy	فرح	Sevinc	欢乐	Blijheid	Rõõm	Ilo	Joie
Pleasure	سرور	Həzz	愉快	Plezier	Nauding	Mielihyvä	Plaisir
Contentment	قناعة	Məmnunluq	满足	Tevredenheid	Rahulolu	Tyytyväisyys	Contentement
Admiration	إعجاب	Heyranlıq	赞赏	Bewondering	Imetlus	Ihailu	Admiration
Love	حب	Sevgi	爱	Liefde	Armastus	Rakkaus	Amour
Relief	طمأنينة	Rahatlama (yungullesme)	如释重负	Opluchting	Kergendus	Helpotus	Soulagement
Compassion	شفقة	Mərhəmət	同情	Medelijden	Kaastunne	Myötätunto	Compassion
Sadness	حزن	Kədər	悲伤	Verdriet	Kurbus	Suru	Tristesse
Guilt	ذَنْب	Günah	内疚	Schuld	Süü	Syyllisyys	Culpabilité
Regret	ندم	Təəssüf	后悔	Spijt	Kahetsus	Katumus	Regret
Shame	عار	Utanma	羞愧	Schaamte	Häbi	Häpeä	Honte
Disappointment	خيبة أمل	Məyusluq	失望	Ontgoocheling	Pettumus	Pettymys	Déception
Fear	خوف	Qorxu	恐惧	Angst	Hirm	Pelko	Peur
Disgust	قرف	Iyrənmə	厌恶	Walging	Vastikus	Inho	Dégoût
Contempt	احتقار	İkrah	轻视	Minachting	Põlgus	Halveksunta	Mépris
Hate	كراهية	Nifrət	憎恨	Haat	Vihkamine	Viha	Haine
Anger	غضب	Hirs	忿怒	Kwaadheid	Viha	Suuttuminen	Colère

German	Georgian	Greek	Hebrew	Italian	Lithuanian	Norwegian
Interesse	ინტერესი	Ενδιαφέρον	עניין	Interesse	Susidomėjimas	Interesse
Belustigung	ხალისიანობა	Διασκέδαση	שעשוע	Divertimento	Linksmumas	Fornøyelse
Stolz	სიამაყე	Υπερηφάνεια	גאווה	Orgoglio	Išdidumas	Stolthet
Freude	სიხარული	Χαρά	שמחה	Gioia	Džiaugsmas	Glede
Vergnügen	სიამოვნება	Ευχαρίστηση	הנאה	Piacere	Malonumas	Nytelse
Zufriedenheit	კმაყოფილება	Ικανοποίηση	שביעות רצון	Contentezza	Pasitenkinimas	Tilfredshet
Bewunderung	აღფრთოვანება	Θαυμασμός	הערצה	Ammirazione	Žavėjimasis	Beundring
Liebe	სიყვარული	Αγάπη	אהבה	Amore	Meilė	Kjærlighet
Erleichterung	შვება	Ανακούφιση	הקלה	Sollievo	Palengvėjimas	Lettelse
Mitgefühl	თანაგრძნობა	Συμπόνια	חמלה	Compassione	Užuojauta	Medfølelse
Trauer	სევდა	Θλίψη	עצבות	Tristezza	Liūdesys	Tristhet
Schuld	დამნაშავეობა	Ενοχή	אשמה	Colpa	Kaltė	Skyldfølelse
Bereuen	სინანული	Μετάνοια	חרטה	Rimpianto	Apgailestavimas	Anger
Scham	სირცხვილი	Ντροπή	בושה	Vergogna	Gėda	Skam
Enttäuschung	გაწბილება	Απογοήτευση	אכזבה	Delusione	Nusivylimas	Skuffelse
Angst	შიში	Φόβος	פחד	Paura	Baimė	Frykt
Ekel	ზიზღი	Αηδία	גועל	Disgusto	Pasibjaurėjimas	Avsky
Verachtung	უპატივცემულობა	Περιφρόνηση	בוז	Disprezzo	Panieka	Forakt
Hass	სიძულვილი	Μίσος	שנאה	Odio	Neapykanta	Hat
Wut	მრისხანება	Θυμός	כעס	Collera	Pyktis	Sinne

Persian	Polish	Russian	Serbian	Spanish	Swedish	Ukrainian
علاقه و توجه	Zainteresowanie	Заинтересованность	Interesovanje	Interés	Intresse	Зацікавленість
سرگرمی	Rozbawienie	Весёлость	Zabava	Diversión	Underhållning	Веселість
افتخار	Duma	Гордость	Ponos	Orgullo	Stolthet	Гордість
مسرت	Radość	Радость	Radost	Alegría	Glädje	Радість
لذت	Przyjemność	Удовольствие	Zadovoljstvo	Placer	Njutning	Задоволення
خرسندی	Zadowolenie	Удовлетворенность	Ispunjenost	Satisfacción	Belåtenhet	Задоволеність
تحسین	Podziw	Восхищение	Divljenje	Admiración	Beundran	Захоплення
عشق	Miłość	Любовь`	Ljubav	Amor	Kärlek	Любов
آسودگی	Uczucie ulgi	Облегчение	Olakšanje	Alivio	Lättnad	Полегшення
دلسوزی و شفقت	Współczucie	Сострадание	Sažaljenje	Compasión	Medkänsla	Співчуття
اندوه	Smutek	Грусть	Tuga	Tristeza	Ledsamhet	Смуток
گناه	Poczucie winy	Чувство вины	Krivica	Culpabilidad	Skuld	Вина
پشیمانی	Żal/Żałowanie	Сожаление	Žaljenje	Arrepentimiento	Ånger	Жаль
خجالت و شرم	Wstyd	Стыд	Sramota	Vergüenza	Skam	Сором
سرخوردگی	Rozczarowanie	Разочарование	Razočaranje	Decepción	Besvikelse	Розчарування
ترس	Strach	Страх	Strah	Miedo	Rädsla	Страх
انزجار	Obrzydzenie	Отвращение	Gađenje	Asco	Avsmak	Відраза
:خوار شمردن	Pogarda	Презрение	Prezir	Desprecio	Förakt	Презирство
نفرت	Nienawiść	Ненависть	Mržnja	Odio	Hat	Ненависть
خشم	Złość	Гнев	Ljutnja	Cólera	Ilska	Гнів

Table S 4. Colour terms in all the languages used in this study (divided into three tables).

English	Arabic	Azerbaijani	Chinese (Simplified Mandarin)	Dutch	Estonian	Finnish	French
White	ابيض	Ağ	白色	Wit	Valge	Valkoinen	Blanc
Black	اسود	Qara	黑色	Zwart	Must	Musta	Noir
Grey	رمادي	Boz	灰色	Grijs	Hall	Harmaa	Gris
Red	احمر	Qırmızı	红色	Rood	Punane	Punainen	Rouge
Orange	برتقالي	Narıncı	桔色	Oranje	Oranž	Oranssi	Orange
Yellow	اصفر	Sarı	黄色	Geel	Kollane	Keltainen	Jaune
Green	اخضر	Yaşıl	绿色	Groen	Roheline	Vihreä	Vert
Turquoise	ازرق سماوي	Mavi	青色	Turquoise	Türkiis	Turkoosi	Turquoise
Blue	ازرق	Göy	蓝色	Blauw	Sinine	Sininen	Bleu
Purple	بنفسجي	Bənövşəyi	紫色	Paars	Lilla	Violetti	Violet
Brown	بني	Qəhvəyi	棕色	Bruin	Pruun	Ruskea	Brun
Pink	زهري	Çəhrayı	粉色	Roze	Roosa	Pinkki	Rose

German	Georgian	Greek	Hebrew	Italian	Lithuanian	Norwegian
Schwarz	თეთრი	Μαύρο	לבן	Bianco	Balta	Hvit
Blau	შავი	Μπλέ	שחור	Nero	Juoda	Svart
Braun	ნაცრისფერი	Καφέ	אפור	Grigio	Pilka	Grå
Grün	წითელი	Πράσινο	אדום	Rosso	Raudona	Rød
Grau	ნარინჯისფერი	Γκρι	כתום	Arancione	Oranžinė	Oransje
Orange	ყვითელი	Πορτοκαλί	צהוב	Giallo	Geltona	Gul
Gelb	მწვანე	Ροζ	ירוק	Verde	Žalia	Grøn
Lila	ცისფერი	Μωβ	תכלת	Turchese	Žydra/Turkio	Turkis
Rot	ლურჯი	Κόκκινο	כחול	Blu	Mėlyna	Blå
Türkis	იასამნისფერი	Γαλάζιο	סגול	Viola	Violetinė	Lilla
Weiss	ყავისფერი	Λευκό	חום	Marrone	Ruda	Brun
Rosa	ვარდისფერი	Κίτρινο	ורוד	Rosa	Rožinė	Rosa

Persian	Polish	Russian	Serbian	Spanish	Swedish	Ukrainian
سفید	Biały	Белый	Bela	Blanco	Vit	Білий
سیاه	Czarny	Чёрный	Crna	Negro	Svart	Чорний
خاکستری	Szary	Серый	Siva	Gris	Grå	Сірий
قرمز	Czerwony	Красный	Crvena	Rojo	Röd	Червоний
نارنجی	Pomarańczowy	Оранжевый	Narandzasta	Naranja	Orange	Помаранчевий
زرد	Żółty	Жёлтый	Zuta	Amarillo	Gul	Жовтий
سبز	Zielony	Зелёный	Zelena	Verde	Grön	Зелений
فیروزه ای	Turkusowy	Голубой	Tirkizna	Turquesa	Turkos	Блакитний
آبی	Niebieski	Синий	Plava	Azul	Blå	Синій
بنفش	Fioletowy	Фиолетовый	Ljubicasta	Violeta	Lila	Фіолетовий
قهوه ای	Brązowy	Коричневый	Smedja	Marron	Brun	Коричневий
صورتی	Różowy	Розовый	Roza	Rosa	Rosa	Рожевий

Table S 5. Mean number of associated emotions with each colour term for all nations together.

Standard deviations (SD), standard errors (SE), and 95% confidence intervals (CI) are also displayed.

Colour	Mean	95%CI lower	95%CI higher
black	3.83	3.73	3.94
blue	3.1	3	3.2
brown	2.25	2.16	2.35
green	3.11	3.01	3.21
grey	2.86	2.76	2.96
orange	2.83	2.73	2.93
pink	3.1	3.01	3.2
purple	2.94	2.84	3.04
red	3.84	3.74	3.95
turquoise	2.84	2.75	2.94
white	2.85	2.75	2.95
yellow	3.09	2.99	3.18

Table S 6. Colour-emotion association matrices in 30 nations.

Table S 7. Nation-to-nation colour-emotion association pattern similarities (correlations).

Table S 8. Colour-emotion association matrices by sex.

Table S 9. Colour-emotion association matrices by age group.

For these tables, please refer to the online supplement of the published article:

https://journals.sagepub.com/doi/suppl/10.1177/0956797620948810

Table S 10. Average colour-emotion association pattern similarities for each of the 12 colour terms across all nations

			Range		*CI 95%*	
Color term	Similarity	Variance	Minimum	Maximum	Lower	Upper
black	0.905	0.004	0.645	0.981	0.882	0.929
blue	0.862	0.008	0.612	0.966	0.830	0.893
brown	0.865	0.020	0.340	0.968	0.814	0.916
green	0.900	0.002	0.784	0.969	0.885	0.915
grey	0.914	0.019	0.225	0.981	0.865	0.963
orange	0.916	0.013	0.375	0.981	0.876	0.957
pink	0.925	0.002	0.843	0.991	0.910	0.940
purple	0.659	0.095	-0.179	0.912	0.548	0.769
red	0.892	0.008	0.595	0.988	0.861	0.923
turquoise	0.911	0.003	0.725	0.971	0.891	0.930
white	0.862	0.015	0.297	0.953	0.818	0.905
yellow	0.849	0.057	-0.203	0.988	0.764	0.934

Table S 11. Emotion intensity pattern similarities by nation and colour term.

Table S 12. Linguistics distances for each nation-nation pair of the current study.

Table S 13. Geographic distances for each nation-nation pair of the current study.

Table S 14. Coordinates of the population-weighted mean geographical centres of each nation or coordinates of the most populated cities.

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Chapter 3.

Supplemental Tables

Table S 15. Colour and emotion terms in English and French.

The validated French version of emotion terms taken from http://www.affective-sciences.org/gew. French has two basic terms for the "brown" category – *brun* and marron (Forbes, 1979). We chose *brun* since it has the least contextually restricted meaning (N. C. W. Spence, 1989). However, we hypothesise that marron would result in very similar affective associations to *brun*, since both *brun* and marron map to comparable perceptual colours (N. C. W. Spence, 1989). Also see Table S 3 and Table S 4.

English	**French**
Red	Rouge
Orange	Orange
Yellow	Jaune
Green	Vert
Turquoise	Turquoise
Blue	Bleu
Purple	Violet
Pink	Rose
Brown	Brun
White	Blanc
Grey	Gris
Black	Noir

Interest	Intérêt
Amusement	Amusement
Pride	Fierté
Joy	Joie
Pleasure	Plaisir
Contentment	Contentement
Admiration	Admiration
Love	Amour
Relief	Soulagement
Compassion	Compassion
Sadness	Tristesse
Guilt	Culpabilité
Regret	Regret
Shame	Honte
Disappointment	Déception
Fear	Peur
Disgust	Dégoût
Contempt	Mépris
Hate	Haine
Anger	Colère

Table S 16. This colour-emotion association matrix for pooled data.

It indicates the proportion of participants who endorse given colours as being associated with given emotions. These proportions were derived from pooled data, i.e., colour-emotion associations for both colour terms and colour patches.

	BLACK	BLUE	BROWN	GREEN	GREY	ORANGE	PINK	PURPLE	RED	TURQUOISE	WHITE	YELLOW
Interest	.08	.30	.08	.33	.08	.23	.17	.20	.18	.29	.21	.20
Amusement	.03	.26	.05	.36	.03	.41	.42	.18	.13	.33	.08	.44
Pride	.09	.24	.05	.18	.05	.17	.11	.14	.23	.18	.22	.26
Joy	.02	.32	.05	.33	.03	.48	.55	.14	.17	.45	.18	.61
Pleasure	.04	.30	.08	.30	.04	.35	.63	.19	.39	.41	.14	.36
Contentment	.06	.33	.10	.31	.07	.28	.33	.17	.13	.33	.25	.24
Admiration	.05	.36	.07	.19	.06	.26	.33	.12	.20	.27	.23	.36
Love	.03	.12	.06	.11	.04	.07	.63	.17	.68	.11	.15	.10
Relief	.04	.38	.09	.22	.11	.14	.23	.14	.07	.33	.44	.16
Compassion	.05	.25	.10	.14	.08	.16	.32	.20	.17	.20	.25	.19
Sadness	.45	.27	.11	.06	.61	.08	.04	.19	.05	.11	.12	.04
Guilt	.34	.15	.14	.14	.32	.08	.05	.20	.13	.05	.11	.12
Regret	.45	.17	.20	.11	.55	.08	.05	.15	.11	.08	.17	.07
Shame	.27	.06	.18	.11	.22	.08	.08	.16	.28	.04	.08	.11
Disappointment	.48	.12	.20	.09	.54	.08	.05	.19	.08	.07	.11	.08
Fear	.45	.16	.06	.11	.21	.05	.05	.11	.16	.06	.12	.12
Disgust	.35	.02	.50	.27	.20	.08	.06	.19	.11	.05	.04	.18
Contempt	.43	.06	.26	.12	.26	.15	.05	.16	.20	.05	.07	.15
Hate	.47	.03	.07	.08	.11	.11	.04	.13	.51	.04	.03	.05
Anger	.34	.03	.08	.08	.10	.11	.04	.12	.73	.04	.02	.12

Table S 17. This colour-emotion association matrix for colour terms.

It indicates the proportion of participants who endorse given colours as being associated with given emotions. These proportions were derived from colour-emotion associations for colour terms.

Terms	BLACK	BLUE	BROWN	GREEN	GREY	ORANGE	PINK	PURPLE	RED	TURQUOISE	WHITE	YELLOW
Interest	.10	.26	.12	.35	.08	.26	.15	.27	.19	.23	.22	.19
Amusement	.04	.22	.06	.45	.05	.46	.47	.22	.12	.29	.10	.40
Pride	.13	.29	.06	.19	.06	.18	.09	.22	.21	.21	.24	.19
Joy	.04	.36	.08	.36	.05	.49	.63	.19	.15	.50	.22	.56
Pleasure	.04	.27	.08	.29	.06	.36	.72	.22	.41	.41	.13	.35
Contentment	.06	.26	.14	.33	.06	.28	.29	.19	.15	.35	.27	.19
Admiration	.06	.32	.09	.21	.08	.26	.28	.19	.15	.26	.28	.31
Love	.05	.12	.05	.13	.05	.10	.72	.15	.74	.09	.17	.10
Relief	.05	.40	.09	.22	.06	.12	.23	.13	.05	.31	.49	.17
Compassion	.06	.28	.13	.15	.08	.17	.28	.21	.15	.14	.29	.15
Sadness	.58	.31	.09	.05	.64	.06	.06	.17	.06	.12	.15	.05
Guilt	.37	.19	.15	.13	.33	.08	.06	.18	.14	.06	.10	.15
Regret	.59	.22	.19	.09	.60	.08	.04	.17	.10	.06	.18	.10
Shame	.32	.10	.21	.13	.24	.09	.05	.15	.35	.05	.10	.13
Disappointment	.54	.15	.14	.08	.60	.08	.06	.17	.08	.08	.15	.10
Fear	.55	.21	.04	.14	.26	.05	.05	.13	.12	.05	.12	.15
Disgust	.31	.04	.38	.29	.26	.08	.06	.18	.13	.08	.06	.26
Contempt	.53	.09	.22	.13	.29	.14	.05	.15	.23	.06	.09	.18
Hate	.67	.04	.08	.12	.14	.13	.05	.14	.63	.06	.05	.08
Anger	.47	.05	.10	.09	.12	.14	.05	.14	.83	.06	.03	.15

Table S 18. This colour-emotion association matrix for colour patches.

It indicates the proportion of participants who endorse given colours as being associated with given emotions. These proportions were derived from colour-emotion associations for colour patches.

Patches	BLACK	BLUE	BROWN	GREEN	GREY	ORANGE	PINK	PURPLE	RED	TURQUOISE	WHITE	YELLOW
Interest	.04	.37	.04	.31	.07	.20	.19	.09	.17	.37	.20	.22
Amusement	.02	.31	.02	.24	.00	.33	.35	.13	.15	.39	.04	.50
Pride	.04	.17	.02	.17	.02	.17	.15	.04	.26	.15	.19	.35
Joy	.00	.26	.02	.28	.00	.48	.44	.07	.20	.37	.13	.69
Pleasure	.04	.35	.07	.30	.00	.33	.50	.15	.37	.41	.17	.37
Contentment	.06	.44	.04	.28	.07	.28	.39	.15	.09	.30	.22	.31
Admiration	.02	.43	.04	.17	.04	.26	.39	.02	.26	.30	.15	.43
Love	.00	.13	.07	.07	.02	.02	.50	.20	.59	.15	.13	.09
Relief	.02	.35	.09	.22	.19	.17	.24	.17	.09	.35	.37	.15
Compassion	.02	.20	.06	.13	.09	.15	.37	.19	.19	.30	.19	.24
Sadness	.26	.22	.15	.07	.57	.09	.00	.22	.04	.11	.07	.02
Guilt	.30	.09	.13	.15	.30	.09	.04	.22	.11	.04	.11	.07
Regret	.24	.11	.20	.13	.48	.09	.07	.13	.11	.09	.15	.02
Shame	.20	.00	.15	.09	.19	.06	.11	.17	.19	.02	.04	.07
Disappointment	.41	.07	.30	.11	.44	.09	.02	.22	.07	.06	.06	.06
Fear	.30	.09	.09	.07	.15	.04	.04	.07	.22	.07	.13	.07
Disgust	.41	.00	.67	.22	.13	.09	.06	.20	.07	.02	.00	.07
Contempt	.30	.02	.31	.11	.20	.17	.06	.17	.17	.02	.04	.11
Hate	.19	.02	.06	.04	.06	.07	.02	.11	.33	.00	.00	.02
Anger	.15	.00	.06	.07	.07	.06	.02	.09	.59	.00	.00	.07

Table S 19. Valence, arousal, and power loadings for each colour, separated by term and patch.

The term *Bias* represents the mean loading; 95% CI represents 95% confidence intervals of the mean. Same information as in Figure 3.3.

Colour presentation mode	Colour	Valence		Arousal		Power	
		Bias	*95% CI*	Bias	*95% CI*	Bias	*95% CI*
Colour term	Red	-0.33	[-0.86, 0.19]	2.28	[1.92, 2.65]	1.03	[0.70, 1.36]
	Orange	1.74	[1.24, 2.24]	0.72	[0.30, 1.14]	0.97	[0.62, 1.33]
	Yellow	1.26	[0.61, 1.91]	0.80	[0.49, 1.10]	1.05	[0.74, 1.36]
	Green	1.44	[0.76, 2.11]	0.15	[-0.17, 0.48]	0.90	[0.58, 1.22]
	Turquoise	2.09	[1.59, 2.61]	0.22	[-0.11, 0.55]	0.45	[0.11, 0.79]
	Blue	1.37	[0.83, 1.92]	-0.42	[-0.80, -0.05]	-0.53	[-0.96, -0.09]
	Purple	0.41	[-0.22, 1.04]	-0.13	[-0.48, 0.22]	0.15	[-0.19, 0.50]
	Pink	3.32	[2.76, 3.89]	1.76	[1.42, 2.09]	0.24	[-0.04, 0.53]
	Brown	-0.71	[-1.07, -0.34]	-0.63	[-0.86, -0.39]	-0.06	[-0.37, 0.24]
	Grey	1.37	[0.88, 1.86]	-0.86	[-1.22, -0.50]	-0.94	[-1.23, -0.64]
	White	-2.85	[-3.37, -2.32]	-1.36	[-1.63, -1.09]	-1.39	[-1.73, -1.04]
	Black	-4.28	[-4.95, -3.61]	-0.33	[-0.64, -0.03]	0.18	[-0.19, 0.55]
Colour patch	Red	0.46	[-0.38, 1.31]	1.76	[1.34, 2.18]	0.80	[0.40, 1.19]
	Orange	1.54	[0.74, 2.33]	0.24	[-0.23, 0.71]	0.65	[0.23, 1.06]
	Yellow	2.76	[2.04, 3.48]	0.83	[0.46, 1.21]	1.02	[0.61, 1.42]
	Green	1.09	[0.15, 2.04]	-0.28	[-0.74, 0.19]	0.39	[-0.02, 0.80]
	Turquoise	2.65	[1.91, 3.39]	-0.02	[-0.39, 0.35]	0.09	[-0.35, 0.54]
	Blue	2.39	[1.59, 3.19]	-0.28	[-0.72, 0.16]	-0.46	[-0.91, -0.02]
	Purple	-0.41	[-1.23, 0.42]	-0.33	[-0.65, -0.02]	-0.56	[-1.02, -0.09]
	Pink	3.09	[2.32, 3.87]	0.87	[0.39, 1.35]	-0.32	[-0.76, 0.13]
	Brown	-1.65	[-2.18, -1.11]	-1.17	[-1.47, -0.86]	0.13	[-0.31, 0.56]
	Grey	1.19	[0.60, 1.78]	-0.59	[-0.92, -0.26]	-0.59	[-0.90, -0.29]
	White	-2.09	[-2.76, -1.43]	-1.46	[-1.78, -1.15]	-1.69	[-2.08, -1.29]
	Black	-2.50	[-3.19, -1.81]	-0.57	[-0.960, -0.19]	-0.06	[-0.55, 0.44]

Chapter 4.

Supplemental Tables

Table S 20. Demographic information of participants by country.
Language refers to the language in which the survey was completed.

Country	Language(s) (% of participants)	N (males)	Age (mean, range)
Argentina	Spanish (95.4)	65 (21)	36.98 (17-71)
Algeria	French (50.9) & Arabic (36.8) & English (10.5)	57 (21)	28.47 (18-72)
Australia	English (94.4)	54 (14)	36.13 (19-76)
Austria	German (92.5)	53 (8)	30.74 (20-60)
Azerbaijan	Azerbaijani (99.5)	433 (114)	36.42 (17-70)
Bangladesh	Bengali (95.2)	21 (10)	30.48 (21-62)
Belgium	Dutch (85.4) & English (7.8)	103 (22)	39.06 (19-87)
Bulgaria	Bulgarian (96.9)	32 (13)	39.34 (23-69)
China	Mandarin Chinese (97.8)	181 (52)	34.29 (17-80)
Colombia	Spanish (100)	102 (45)	36.61 (18-74)
Croatia	Croatian (100)	70 (13)	39.64 (18-60)
Cyprus	Greek (79.0) & Turkish (19.8)	324 (88)	30.45 (16-85)
Denmark	Danish (44.8) & English (24.1) & Icelandic (13.8)	29 (12)	44.90 (24-72)
Egypt	Arabic (100)	159 (36)	28.89 (16-65)
Estonia	Estonian (98.5)	131 (16)	38.75 (19-70)
Finland	Finnish (97.8)	138 (17)	32.46 (19-71)
France	French (83.9) & Polish (4.3) & Arabic (3.2)	93 (24)	38.84 (19-75)
Gabon	French (100)	30 (19)	30.70 (24-54)
Georgia	Georgian (97.7)	133 (40)	32.17 (16-73)

Germany	German (85.2) & English (6.0)	250 (36)	33.14 (16-82)
Greece	Greek (100)	499 (84)	30.05 (16-76)
Iceland	Icelandic (97.2)	71 (12)	36.49 (21-62)
Iran	Persian (97.6)	123 (16)	32.74 (16-79)
Israel	Hebrew (92.7)	82 (15)	37.43 (21-67)
Italy	Italian (86.1) & English (2.6)	115 (40)	38.00 (19-80)
Japan	Japanese (96.2)	25 (11)	29.88 (19-48)
Kenya	English (96.0)	26 (11)	29.04 (17-51)
Latvia	Latvian (85.7) & Russian (10.7)	28 (4)	26.11 (19-57)
Lebanon	English (64.9) & Arabic (29.7)	74 (19)	27.32 (17-71)
Lithuania	Lithuanian (81.0) & English (17.5)	126 (19)	34.48 (16-77)
Mexico	Spanish (98.3)	120 (51)	35.86 (16-78)
Netherlands	Dutch (61.3) & English (36.1)	119 (43)	39.44 (17-71)
New Zealand	English (96.0)	223 (55)	26.22 (18-67)
Nigeria	English (100)	127 (55)	37.92 (19-65)
Norway	Norwegian (96.0)	275 (34)	34.31 (18-79)
Peru	Spanish (100)	22 (4)	48.95 (24-82)
Poland	Polish (98.2)	164 (38)	30.00 (17-70)
Portugal	Portuguese (96.8)	31 (2)	27.06 (18-55)
Romania	Romanian (95.8)	25 (4)	24.04 (17-39)
Russia	Russian (97.4)	115 (46)	36.14 (16-78)
Saudi Arabia	Arabic (98.6)	141 (49)	33.21 (18-85)
Serbia	Serbian (98.2)	109 (28)	41.09 (19-78)
South Africa	English (92.0)	25 (12)	37.60 (26-58)
South Korea	Korean (95.8)	24 (2)	26.50 (20-53)
Spain	Spanish (96.0)	201 (55)	34.41 (19-75)
Sweden	Swedish (93.6)	265 (42)	36.14 (20-82)
Switzerland	French (74.0) & German (7.8) & English	346 (102)	30.12 (17-79)

	(5.5) & Italian (3.8)		
Taiwan	Mandarin Chinese (95.0)	60 (19)	26.37 (18-54)
Thailand	Thai (96.7)	30 (7)	39.83 (25-63)
Togo	French (100)	34 (19)	35.91 (19-69)
Turkey	Turkish (92.3)	91 (26)	30.85 (19-84)
Ukraine	Ukrainian (89.2) & Russian (8.1)	74 (10)	38.15 (18-87)
United Kingdom	English (81.1) & Lithuanian (3.9) & Arabic (2.4)	206 (62)	38.97 (16-71)
USA	English (86.1) & Arabic (3.3) & Spanish (2.6)	151 (43)	36.97 (16-75)
Zimbabwe	English (100)	20 (9)	37.00 (17-63)

Table S 21. Yellow and joy in 40 languages, used in the International Colour-Emotion Association Survey.

Language	"Yellow"	"Joy"
Albanian	E verdhë	Lumturi
Arabic	اصفر	فرح
Arabic (Algeria)	اصفر	فرح
Azerbaijani	Sarı	Sevinc
Bengali	হলুদ	আনন্দ
Bulgarian	Жълт	Радост
Chinese (Mandarin simplified)	黄色	欢乐
Chinese (Mandarin traditional)	黃色	歡樂
Croatian	Zuta	Radost
Danish	Gul	Glæde
Dutch	Geel	Blijheid
English	Yellow	Joy
Estonian	Kollane	Rõõm
Finnish	Keltainen	Ilo
French	Jaune	Joie
Georgian	ყვითელი	სიხარული
German	Gelb	Freude
Greek	Κίτρινο	Χαρά
Hebrew	צהוב	שמחה
Hindi	पीला	मज़ा
Hungarian	Sárga	Vidámság
Icelandic	Gulur	Gleði
Italian	Giallo	Gioia
Japanese	黄色	喜び
Korean	노란색	기쁨
Latvian	Dzeltena	Prieks

Lithuanian	Geltona	Džiaugsmas
Malay	Kuning	Gembira
Norwegian	Gul	Glede
Persian	زرد	مسرت
Polish	Żółty	Radość
Portuguese	Amarelo	Alegria
Portuguese (Brazilian)	Amarelo	Alegria
Romanian	Galben	Bucurie
Russian	Жёлтый	Радость
Serbian	Žuta	Radost
Slovak	Žltá	Radosť
Spanish	Amarillo	Alegría
Swedish	Gul	Glädje
Turkish	Sarı	Sevinç
Ukrainian	Жовтий	Радість

Table S 22. Different language links used in this study

Language	Link
Albanian	http://www2.unil.ch/onlinepsylab/colour_albanian/main.php
Arabic (Egypt & Saudi Arabia)	http://www2.unil.ch/onlinepsylab/colour_arabic/main.php
Arabic (Algeria)	http://www2.unil.ch/onlinepsylab/colour_arabic2/main.php
Armenian	http://www2.unil.ch/onlinepsylab/colour_armenian/main.php
Azerbaijani	http://www2.unil.ch/onlinepsylab/colour_azerbaijani/main.php
Bengali	http://www2.unil.ch/onlinepsylab/colour_bengali/main.php
Bulgarian	http://www2.unil.ch/onlinepsylab/colour_bulgarian/main.php
Chinese (Simplified Mandarin)	http://www2.unil.ch/onlinepsylab/colour_china/main.php
Chinese (Traditional Mandarin)	http://www2.unil.ch/onlinepsylab/colour_trad_chinese/main.php
Croatian	http://www2.unil.ch/onlinepsylab/colour_croatian/main.php
Danish	http://www2.unil.ch/onlinepsylab/colour_danish/main.php
Dutch	http://www2.unil.ch/onlinepsylab/colour_dutch/main.php
English	http://www2.unil.ch/onlinepsylab/colour/main.php
Estonian	http://www2.unil.ch/onlinepsylab/colour_estonian/main.php
Finnish	http://www2.unil.ch/onlinepsylab/colour_finnish/main.php
French	http://www2.unil.ch/onlinepsylab/UNILcouleur/main.php
Georgian	http://www2.unil.ch/onlinepsylab/colour_georgian/main.php
German	http://www2.unil.ch/onlinepsylab/colour_german/main.php
Greek	http://www2.unil.ch/onlinepsylab/colour_greek/main.php
Hebrew	http://www2.unil.ch/onlinepsylab/colour_hebrew/main.php
Hindi	http://www2.unil.ch/onlinepsylab/colour_hindi/main.php
Hungarian	http://www2.unil.ch/onlinepsylab/colour_hungarian/main.php

Icelandic	http://www2.unil.ch/onlinepsylab/colour_icelandic/main.php
Italian	http://www2.unil.ch/onlinepsylab/colour_italian/main.php
Japanese	http://www2.unil.ch/onlinepsylab/colour_japanese/main.php
Korean	http://www2.unil.ch/onlinepsylab/colour_korean/main.php
Latvian	http://www2.unil.ch/onlinepsylab/colour_latvian/main.php
Lithuanian	http://www2.unil.ch/onlinepsylab/colour_lithuanian/main.php
Malay	www2.unil.ch/onlinepsylab/colour_malay/main.php
Norwegian	http://www2.unil.ch/onlinepsylab/colour_norwegian/main.php
Persian	http://www2.unil.ch/onlinepsylab/colour_persian/main.php
Polish	http://www2.unil.ch/onlinepsylab/colour_polish/main.php
Portuguese (Brazilian)	http://www2.unil.ch/onlinepsylab/colour_portuguese/main.php
Portuguese (Portuguese)	http://www2.unil.ch/onlinepsylab/colour_portuguese2/main.php
Romanian	http://www2.unil.ch/onlinepsylab/colour_romanian/main.php
Russian	http://www2.unil.ch/onlinepsylab/colour_russian/main.php
Serbian	http://www2.unil.ch/onlinepsylab/colour_serbian/main.php
Slovak	http://www2.unil.ch/onlinepsylab/colour_slovak/main.php
Spanish	http://www2.unil.ch/onlinepsylab/colour_spanish/main.php
Swedish	http://www2.unil.ch/onlinepsylab/colour_swedish/main.php
Thai	http://www2.unil.ch/onlinepsylab/colour_thai/main.php
Turkish	http://www2.unil.ch/onlinepsylab/colour_turkish/main.php
Ukrainian	http://www2.unil.ch/onlinepsylab/colour_ukrainian/main.php

Table S 23. Geographic and climatological variables per country.

Latitudes are absolute values relative to the equator.

Country	Latitude (°)	Longitude (°)	Precipitation (mm/year)	Sunshine (average % of sunny hours per daytime hours across a year)
Algeria	28.00	3.00	89	65.00
Argentina	-34.00	-64.00	591	57.83
Australia	-27.00	133.00	534	63.14
Austria	47.33	13.33	1110	43.01
Azerbaijan	40.50	47.50	447	50.40
Bangladesh	24.00	90.00	2666	47.17
Belgium	50.83	4.00	847	35.30
China	35.00	105.00	645	40.54
Bulgaria	43.00	25.00	608	49.70
Colombia	4.00	-72.00	3240	39.04
Croatia	45.17	15.50	1113	43.68
Cyprus	35.00	33.00	498	76.76
Denmark	56.00	10.00	703	35.14
Egypt	27.00	30.00	51	80.86
Estonia	59.00	26.00	626	40.02
Finland	64.00	26.00	536	42.42
France	46.00	2.00	867	37.95
Gabon	-1.00	11.75	1831	39.36
Georgia	42.00	43.50	1026	48.22
Germany	51.00	9.00	700	37.12
Greece	39.00	22.00	652	65.02
Iceland	65.00	-18.00	1940	30.27
Iran	32.00	53.00	228	68.40
Israel	31.50	34.75	435	75.59
Italy	42.83	12.83	832	43.72

Japan	36.00	138.00	1668	42.85
Kenya	1.00	38.00	630	56.89
Latvia	57.00	25.00	641	41.37
Lebanon	33.83	35.83	661	67.12
Lithuania	56.00	24.00	656	41.10
Mexico	23.00	-102.00	758	58.33
Netherlands	52.50	5.75	778	37.95
New Zealand	-41.00	174.00	1732	47.00
Nigeria	10.00	8.00	1150	63.20
Norway	62.00	10.00	1414	38.08
Peru	-10.00	-76.00	1738	28.08
Poland	52.00	20.00	600	35.87
Portugal	39.50	-8.00	854	64.06
Romania	46.00	25.00	637	48.29
Russia	60.00	100.00	460	39.52
Saudi Arabia	25.00	45.00	59	74.16
Serbia	44.00	21.00	686	48.22
South Africa	-29.00	24.00	495	85.20
South Korea	37.00	127.50	1274	47.17
Spain	40.00	-4.00	636	59.16
Sweden	62.00	15.00	624	41.58
Switzerland	47.00	8.00	1537	35.75
Taiwan	23.50	121.00	2090	32.08
Thailand	15.00	100.00	1622	60.03
Togo	8.00	1.17	1168	53.29
Turkey	39.00	35.00	593	50.64
Ukraine	49.00	32.00	565	44.63
United Kingdom	54.00	-2.00	1220	37.28
USA (excluding Alaska and Hawaii)	38.00	-97.00	715	57.87
Zimbabwe	-20.00	30.00	657	68.74

Table S 24. Participant count at each stage of exclusion until the final sample was reached.

Complete data are available here: https://forsbase.unil.ch/project/study-public-overview/15126/1672/

Sample size	Description
N = 8934	Extracted data from the online International Colour-Emotion Survey in February 2019
N = 8857	Excluding incomplete responses
N = 8507	Excluding participants who were not fluent in the language of the survey (leaving responses 5-8 only) or did not provide an answer
N = 7618	Excluding colour-blind participants by self-report (leaving participants who responded “no”) or those who did not provide an answer
N = 7219	Excluding participants who were too slow or too quick in completing the survey (leaving those who completed the survey between 3 and 90 min)
N = 7081	Excluding younger than 16 years old participants or those who had missing age information
N = 6945	Excluding participants who were too quick when responding to the first four colour terms (took less than 20 seconds on all four colour terms)
N = 6929	Excluding participants who had missing responses for *yellow*
N = 6625	Excluding participants from the countries, which had fewer than 20 responses in total. This is the final sample

Table S 25. Correlation matrix between the predictors performed by taking each country as an individual data point.

	Absolute latitude	Precipitation	Sunshine
Absolute latitude	1.000	-0.283*	-0.405**
Precipitation	-0.283*	1.000	-0.478***
Sunshine	-0.405**	-0.478***	1.000

*$p < .050$, **$p < .010$, ***$p < .001$

Table S 26. The likelihood of yellow-joy associations in per cent with 95% confidence intervals (CI) per country.

Country	Likelihood	95% lower CI of likelihood	95% higher CI of likelihood
Algeria	29.82	17.58	42.07
Argentina	50.77	38.28	63.25
Australia	62.96	49.66	76.27
Austria	62.26	48.78	75.75
Azerbaijan	10.62	7.71	13.54
Bangladesh	28.57	7.50	49.64
Belgium	62.14	52.61	71.66
Bulgaria	53.13	34.85	71.40
China	44.20	36.89	51.50
Colombia	58.82	49.11	68.54
Croatia	57.14	45.26	69.03
Cyprus	28.09	23.17	33.01
Denmark	51.72	32.38	71.07
Egypt	5.66	2.03	9.29
Estonia	70.99	63.12	78.87
Finland	87.68	82.13	93.23
France	59.14	48.96	69.32
Gabon	36.67	18.36	54.97
Georgia	33.83	25.69	41.98
Germany	64.00	58.01	69.99
Greece	34.87	30.67	39.07
Iceland	78.87	69.14	88.60
Iran	28.46	20.37	36.54
Israel	43.90	32.93	54.87
Italy	53.04	43.78	62.30
Japan	69.23	50.22	88.24
Kenya	36.00	15.78	56.22

Latvia	75.00	57.90	92.10
Lebanon	35.14	24.00	46.27
Lithuania	64.29	55.80	72.77
Mexico	55.00	45.97	64.03
Netherlands	62.18	53.34	71.03
New Zealand	73.54	67.71	79.38
Nigeria	35.43	27.00	43.87
Norway	67.64	62.07	73.20
Peru	45.45	22.86	68.05
Poland	57.32	49.67	64.97
Portugal	64.52	46.68	82.36
Romania	32.00	12.35	51.65
Russia	47.83	38.56	57.09
Saudi Arabia	24.11	16.97	31.26
Serbia	36.70	27.50	45.89
South Africa	60.00	39.36	80.64
South Korea	50.00	28.43	71.57
Spain	48.76	41.79	55.73
Sweden	66.04	60.30	71.78
Switzerland	56.36	51.11	61.61
Taiwan	55.00	42.04	67.96
Thailand	46.67	27.72	65.61
Togo	32.35	15.78	48.92
Turkey	25.27	16.17	34.38
UK	65.05	58.48	71.61
Ukraine	45.95	34.32	57.57
USA	60.93	53.06	68.80
Zimbabwe	25.00	4.21	45.79

Table S 27. The likelihood (in per cent) of the associations between yellow and 10 positive emotions in the 55 studied countries.

	Admiration	Amusement	Compassion	Contentment	Interest	Joy	Love	Pleasure	Pride	Relief
Algeria	10.53	33.33	5.26	10.53	10.53	29.82	1.75	26.32	8.77	8.77
Argentina	21.54	36.92	16.92	26.15	30.77	50.77	18.46	26.15	18.46	20.00
Australia	14.81	31.48	20.37	31.48	29.63	62.96	18.52	33.33	12.96	12.96
Austria	18.87	18.87	9.43	39.62	33.96	62.26	9.43	39.62	16.98	32.08
Azerbaijan	8.78	15.01	5.31	8.08	10.62	10.62	4.85	8.78	4.85	6.24
Bangladesh	14.29	19.05	9.52	19.05	9.52	28.57	23.81	9.52	14.29	14.29
Belgium	16.50	46.60	6.80	34.95	17.48	62.14	9.71	57.28	23.30	20.39
Bulgaria	12.50	56.25	3.13	28.13	18.75	53.13	15.63	28.13	12.50	12.50
China	30.39	42.54	14.92	35.91	27.62	44.20	17.13	41.99	27.07	10.50
Colombia	31.37	39.22	13.73	35.29	20.59	58.82	8.82	16.67	25.49	17.65
Croatia	15.71	38.57	8.57	31.43	27.14	57.14	18.57	37.14	11.43	14.29
Cyprus	16.67	25.00	10.80	16.36	19.75	28.09	12.35	18.52	10.80	13.27
Denmark	10.34	31.03	0.00	13.79	17.24	51.72	0.00	24.14	6.90	20.69
Egypt	4.40	8.18	5.03	3.14	5.66	5.66	2.52	5.03	4.40	1.89
Estonia	16.79	54.96	4.58	29.01	24.43	70.99	14.50	24.43	17.56	20.61
Finland	26.81	55.80	13.77	42.75	37.68	87.68	12.32	42.75	17.39	28.99
France	29.03	45.16	9.68	26.88	21.51	59.14	8.60	34.41	22.58	10.75
Gabon	36.67	13.33	6.67	10.00	16.67	36.67	6.67	16.67	16.67	16.67
Georgia	25.56	46.62	8.27	18.05	20.30	33.83	8.27	20.30	12.78	9.77

Germany	15.20	31.20	9.60	35.20	31.20	64.00	8.40	48.40	18.40	26.40
Greece	13.63	24.45	7.82	14.63	20.84	34.87	6.81	22.24	14.03	11.22
Iceland	23.94	52.11	8.45	32.39	39.44	78.87	11.27	12.68	30.99	42.25
Iran	13.01	27.64	8.94	17.07	15.45	28.46	6.50	22.76	10.57	15.45
Israel	9.76	30.49	6.10	15.85	15.85	43.90	7.32	35.37	14.63	8.54
Italy	13.91	40.87	6.09	44.35	26.09	53.04	9.57	23.48	12.17	22.61
Japan	53.85	61.54	3.85	46.15	30.77	69.23	11.54	46.15	38.46	23.08
Kenya	28.00	28.00	4.00	12.00	16.00	36.00	0.00	24.00	20.00	8.00
Latvia	28.57	50.00	14.29	21.43	17.86	75.00	17.86	35.71	21.43	17.86
Lebanon	13.51	31.08	13.51	12.16	13.51	35.14	5.41	17.57	10.81	10.81
Lithuania	29.37	64.29	12.70	33.33	28.57	64.29	19.05	40.48	20.63	26.98
Mexico	26.67	45.83	9.17	16.67	20.00	55.00	5.00	13.33	18.33	14.17
Netherlands	15.97	32.77	9.24	18.49	22.69	62.18	9.24	54.62	12.61	16.81
New Zealand	31.84	52.47	27.35	36.32	36.77	73.54	14.80	52.47	28.70	21.97
Nigeria	35.43	34.65	12.60	7.87	33.86	35.43	25.98	38.58	12.60	19.69
Norway	16.00	38.18	13.09	30.18	29.09	67.64	14.91	26.91	23.27	24.73
Peru	27.27	40.91	9.09	9.09	27.27	45.45	9.09	9.09	31.82	4.55
Poland	10.37	39.02	3.66	34.76	19.51	57.32	6.10	36.59	8.54	11.59
Portugal	29.03	45.16	19.35	45.16	29.03	64.52	12.90	25.81	16.13	16.13
Romania	12.00	28.00	0.00	8.00	12.00	32.00	8.00	28.00	20.00	4.00
Russia	25.22	40.00	2.61	14.78	13.91	47.83	8.70	24.35	8.70	6.96

Saudi Arabia	17.73	26.95	6.38	7.09	12.77	24.11	4.26	25.53	14.18	7.80
Serbia	14.68	33.94	4.59	24.77	28.44	36.70	8.26	27.52	11.93	13.76
South Africa	32.00	52.00	28.00	24.00	32.00	60.00	24.00	44.00	20.00	20.00
South Korea	37.50	58.33	12.50	50.00	50.00	50.00	20.83	70.83	41.67	41.67
Spain	18.41	39.30	7.96	20.40	23.88	48.76	6.47	9.95	16.92	9.45
Sweden	18.87	35.85	15.47	27.17	36.60	66.04	8.68	27.17	19.25	23.77
Switzerland	23.12	35.26	12.72	26.88	23.41	56.36	8.67	35.26	19.94	17.34
Taiwan	30.00	51.67	11.67	45.00	35.00	55.00	23.33	56.67	33.33	13.33
Thailand	36.67	46.67	13.33	16.67	20.00	46.67	0.00	33.33	13.33	10.00
Togo	35.29	26.47	38.24	23.53	26.47	32.35	14.71	20.59	35.29	14.71
Turkey	9.89	32.97	5.49	12.09	15.38	25.27	12.09	14.29	7.69	13.19
Ukraine	22.97	54.05	5.41	18.92	29.73	45.95	6.76	27.03	16.22	10.81
United Kingdom	14.56	36.89	10.68	25.24	23.79	65.05	9.71	33.01	11.17	11.65
United States	16.56	40.40	13.25	28.48	32.45	60.93	11.26	37.75	17.88	17.22
Zimbabwe	15.00	15.00	5.00	5.00	25.00	25.00	10.00	10.00	15.00	10.00
All countries	18.97	35.55	10.22	23.40	23.59	48.06	10.04	28.53	16.09	15.61

Table S 28. The likelihood (in per cent) of the associations between yellow and 10 negative emotions in the 55 studied countries.

	Anger	Contempt	Disappointment	Disgust	Fear	Guilt	Hate	Regret	Sadness	Shame
Algeria	3.51	7.02	5.26	17.54	7.02	12.28	7.02	12.28	8.77	5.26
Argentina	13.85	18.46	18.46	18.46	15.38	12.31	20.00	13.85	10.77	15.38
Australia	5.56	5.56	1.85	11.11	7.41	5.56	1.85	3.70	0.00	5.56
Austria	9.43	16.98	9.43	28.30	3.77	7.55	9.43	3.77	0.00	13.21
Azerbaijan	8.08	11.32	8.78	13.86	4.16	7.39	11.78	12.01	5.08	11.78
Bangladesh	9.52	14.29	19.05	23.81	4.76	4.76	19.05	4.76	14.29	23.81
Belgium	5.83	7.77	6.80	9.71	6.80	5.83	6.80	4.85	3.88	10.68
Bulgaria	6.25	9.38	0.00	3.13	6.25	6.25	9.38	3.13	3.13	6.25
China	9.39	11.05	7.73	9.39	6.63	8.84	6.08	6.63	8.84	8.29
Colombia	11.76	4.90	3.92	9.80	5.88	7.84	3.92	8.82	9.80	7.84
Croatia	8.57	7.14	4.29	4.29	7.14	5.71	10.00	5.71	5.71	8.57
Cyprus	11.11	12.35	10.19	15.74	7.41	9.88	22.22	7.41	10.49	13.89
Denmark	3.45	3.45	6.90	3.45	6.90	13.79	6.90	3.45	0.00	13.79
Egypt	3.77	13.84	7.55	13.21	6.29	8.81	15.09	6.92	1.26	5.66
Estonia	10.69	2.29	3.82	5.34	2.29	3.05	3.82	3.05	2.29	7.63
Finland	7.25	10.14	5.80	16.67	5.07	6.52	6.52	8.70	2.90	7.25
France	8.60	10.75	6.45	10.75	3.23	1.08	3.23	4.30	1.08	5.38
Gabon	3.33	6.67	6.67	10.00	3.33	10.00	3.33	3.33	3.33	6.67
Georgia	8.27	13.53	15.79	13.53	4.51	2.26	9.77	6.02	8.27	9.77

Germany	8.80	17.20	8.00	18.40	9.20	6.40	9.20	5.20	4.00	9.60
Greece	16.43	16.63	10.22	17.03	10.42	16.83	33.67	7.21	6.01	13.83
Iceland	2.82	1.41	1.41	2.82	2.82	7.04	1.41	4.23	2.82	2.82
Iran	4.88	4.88	8.94	13.82	8.94	2.44	14.63	4.07	5.69	9.76
Israel	14.63	18.29	9.76	18.29	9.76	10.98	25.61	7.32	4.88	9.76
Italy	9.57	5.22	5.22	8.70	3.48	6.09	6.09	6.09	5.22	6.96
Japan	15.38	11.54	3.85	3.85	3.85	3.85	3.85	3.85	3.85	11.54
Kenya	0.00	0.00	0.00	4.00	4.00	0.00	0.00	0.00	0.00	0.00
Latvia	7.14	7.14	10.71	14.29	7.14	7.14	7.14	14.29	7.14	10.71
Lebanon	6.76	8.11	10.81	21.62	8.11	17.57	5.41	13.51	5.41	13.51
Lithuania	13.49	11.90	8.73	12.70	9.52	11.90	12.70	10.32	8.73	14.29
Mexico	13.33	10.00	6.67	10.83	2.50	7.50	5.83	6.67	4.17	10.00
Netherlands	10.92	6.72	8.40	6.72	7.56	8.40	10.92	6.72	4.20	4.20
New Zealand	8.52	12.11	4.93	12.56	8.52	5.83	5.38	4.93	6.73	10.31
Nigeria	7.87	3.94	11.02	11.02	3.94	4.72	10.24	11.02	1.57	7.09
Norway	6.91	7.27	6.55	12.00	6.55	6.91	6.18	7.27	4.73	6.91
Peru	9.09	9.09	4.55	9.09	4.55	9.09	4.55	0.00	4.55	9.09
Poland	21.34	10.98	6.10	14.02	4.88	4.88	4.88	6.71	2.44	8.54
Portugal	0.00	6.45	0.00	16.13	3.23	6.45	0.00	9.68	0.00	12.90
Romania	16.00	12.00	12.00	8.00	0.00	12.00	16.00	4.00	0.00	4.00

Russia	1.74	5.22	3.48	5.22	2.61	3.48	2.61	8.70	3.48	6.09
Saudi Arabia	9.22	7.09	10.64	8.51	4.96	7.80	9.93	7.09	4.96	6.38
Serbia	10.09	11.93	6.42	10.09	6.42	6.42	7.34	7.34	4.59	10.09
South Africa	16.00	16.00	16.00	20.00	20.00	16.00	16.00	16.00	28.00	16.00
South Korea	20.83	12.50	8.33	25.00	8.33	12.50	20.83	12.50	12.50	12.50
Spain	9.95	9.45	9.45	6.47	6.47	5.97	7.46	5.97	4.98	13.93
Sweden	9.06	7.17	7.17	12.08	7.17	3.40	3.02	4.91	2.64	4.15
Switzerland	10.12	13.01	9.25	19.36	9.25	13.29	6.65	9.54	5.20	10.98
Taiwan	3.33	15.00	5.00	5.00	3.33	5.00	3.33	5.00	3.33	3.33
Thailand	3.33	3.33	0.00	6.67	0.00	0.00	6.67	0.00	0.00	0.00
Togo	5.88	2.94	0.00	2.94	5.88	5.88	2.94	2.94	2.94	2.94
Turkey	7.69	15.38	9.89	13.19	7.69	4.40	9.89	8.79	10.99	10.99
Ukraine	2.70	9.46	12.16	8.11	8.11	4.05	2.70	10.81	4.05	8.11
United Kingdom	4.85	7.28	3.88	9.71	6.80	4.37	3.88	5.34	1.94	5.83
United States	7.28	6.62	4.64	8.61	11.26	6.62	5.96	4.64	3.31	9.27
Zimbabwe	10.00	5.00	0.00	5.00	10.00	0.00	10.00	0.00	0.00	0.00
All countries	9.33	10.34	7.74	12.59	6.81	7.77	10.42	7.15	5.07	9.37

Derivation For the Number of Daytime Hours

We defined daytime hours as the number of hours between sunrise and sunset. We define sunrise and sunset as the moments that the centre of the sun crosses the horizon.

To calculate the number of daytime hours, we define a geocentric coordinate system. The z-axis is the rotation axis of the Earth (the North South axis). The x-axis is chosen to be perpendicular to the z-axis, and so that the sun always moves in the x-z plane. In spherical coordinates, the θ coordinate is the angle from the positive z-axis (from the North Pole). The ϕ coordinate describes the angle from the positive x-axis, in the x-y plane.

The relationship between Cartesian and Spherical coordinates is as follows:

$$x = rsin\theta cos\phi$$

$$y = rsin\theta sin\phi$$

$$z = rcos\theta$$

For the Sun, ϕ is zero (by construction) and θ varies sinusoidally throughout the year. At the spring and autumn equinoctes, the angle is 90°. At the summer and winter solstices, the angle is respectively 66.5° and 113.5° (90° plus or minus the axial tilt of the earth, T = 23.5°). The θ coordinate is then:

$\theta_s = 90^o - Tsin(2\pi\,(t-79)/365)$, where t is the day of the year.

A point on Earth, $\vec{p}$, describes a circle in the x-y plane. Its ϕ coordinate varies throughout the day – it is 0° at noon and 180° at midnight. Its θ coordinate is fixed by the latitude, $\theta_p = 90^o - latitude$ The points on this circle where $\vec{p}$ crosses into and out of the half of the Earth lit by the Sun are sunrise and sunset. The number of daytime hours is therefore proportional to the part of this circle that is inside the lit area.

Given the latitude of a point, we can calculate the coordinates where sunrise and sunset occur. At sunrise and sunset, the angle of the sun with the zenith is 90°. Since the inner product of two vectors $\vec{p}$ and $\vec{q}$ is equal to $|\vec{p}||\vec{q}|cos\alpha$, where α is the angle between p and q, at sunrise and sunset the inner product of the vectors representing our point ($\vec{p}$) and the sun ($\vec{q}$) is zero.

Using the fact that the Sun is in the x-z plane, so that it's ϕ coordinate is zero, we transform the position of the sun from spherical into Cartesian coordinates:

$$\vec{s} = r_s(sin\theta_s cos\phi_s, sin\theta_s sin\phi_s, cos\theta_s) = r_s(sin\theta_s, 0, cos\theta_s)$$

We use the fact that the cross product of $\vec{p}$ and $\vec{s}$ is zero to calculate the ϕ coordinate of the sunrise and sunset:

$$\vec{p} \cdot \vec{s} = r_p r_s \left(sin\theta_p cos\phi_p sin\theta_s + cos\theta_p cos\theta_s\right) = 0$$

$$sin\theta_p cos\phi_p sin\theta_s = -cos\theta_p cos\theta_s$$

$$cos\phi_p = \frac{-cos\phi_p cos\phi_s}{sinphi_p sinphi_s} = -cot\phi_p cot\phi_s$$

$$\phi_p = \pm acos\left(-cot\phi_p cot\phi_s\right)$$

The angle ϕ_p of sunrise or sunset is directly related to the number of daytime hours, since it is proportional to the fraction of the circle described by point that has sun:

$$daylighthours = \phi_p \cdot 24\, hours/180\, degrees$$

R code to calculate the daytime hours for each participant at the time of survey completion.

To make the calculation, the day of the year (1st – 365th) when the survey was completed and the latitude of the country of residence are fed to the function. The function assumes that spring equinox is on 20th March (i.e., 79th day of the year).

```
hours_daytime <- function (day_of_year, latitude) {
 earth_axial_tilt = 23.5*pi/180 # in radians
  theta = 0.5*pi - latitude*pi/180  # theta = angle from the
north pole in radians
  theta_s = 0.5*pi - earth_axial_tilt * sin(2*pi*(day_of_year
- 79)/365)  #theta_s = angle of the sun from the north pole in
radians on that day
  x = max(-1/(tan(theta)*tan(theta_s)), -1)
  x = min(x, 1)
  phi = acos(x) #phi angle
  result = 24 * abs(phi)/pi
  return(result)
}
```

Chapter 5.

Supplemental Method Details

Colour Vision Test Scoring and Categorisation

Ishihara test. The Ishihara test (Ishihara, 2000) assesses colour confusion along the red-green axis with a series of plates. On each plate, participants see a larger circle filled with smaller circles of different colours. The smaller circles form different numbers or shapes, which participants have to recognise. The plates are presented perpendicular to participants' eyes with an eye-plate distance of about 50 cm distance. The test takes 3-5 minutes to complete.

Each missed or misread number or shape on the first 11 plates is counted as an error. Participants who make four or more errors are considered colour-blind (Thiadens et al., 2013). Participants who make two or three errors are classified as "unsure". Participants who make one or no errors pass the test. Plates 12 to 14 are used to identify the type of colour blindness and we used readings on two out of three plates. Using this criterion, 48 colour-blind participants were categorised as having deutan-like deficiencies. The type of deficiency could not be determined for 16 colour-blind participants, as they either made other types of errors or could not read any number and/or trace any line on two out of three plates. Five colour-blind participants correctly read the plates. None of the non-colour-blind participants made an error on these plates.

Farnsworth D-15 and Lanthony D-15 tests. Farnsworth D-15 test (Farnsworth, 1947) is a colour arrangement test designed to detect colour vision deficiencies. Lanthony D-15 test (Lanthony, 1978b, 1978a) is a desaturated version (Munsell Chroma 2) of the Farnsworth D-15 test. Lanthony D-15 test is more sensitive than Farnsworth D-15 test and can identify individuals with even mild colour blindness.

We used the magnetic version of the Farnsworth D-15 and Lanthony D-15 tests (Good Lite™) to reduce errors due to smudging or physical damage. In this version, the colour samples are presented as disks in a transparent plastic box. The transparent box is placed on a black sheet which acts as background during testing. The disks are moved with a magnetic stick to arrange them according to similarity starting from the reference disk. Each disk is numbered underneath for scoring (not visible to participants). The test takes 3-5 minutes to complete.

Farnsworth D-15 and Lanthony D-15 tests are scored by recording the sequence of disks selected by the participant. Two types of errors occur in D-15 tests. The neighbour errors occur when two neighbouring disks are exchanged. Neighbour errors are counted if the closest neighbour of a disk is exchanged with the second or third closest neighbour. From the fourth closest neighbour onwards, errors are counted as crossing errors (Hovis et al., 2004), which are most indicative of colour blindness. The total number of errors is an arithmetic sum of neighbour and crossing errors.

The criteria for colour blindness are based on the number of crossing errors (Farnsworth, 1947; Hovis et al., 2004). Participants fail the Farnsworth or Lanthony D-15 test if they make three or more crossing errors. Participants pass the test if they make no crossing errors. Participants who make one or two crossing errors cannot be unequivocally classified as passing or failing the test (classified as "unsure"). Farnsworth D-15 test can differentiate between participants with no colour vision deficiency ("pass") and participants with strong colour vision deficiency ("fail" or "unsure"). Participants with mild colour vision deficiencies would often pass the Farnsworth D-15 test or be classified as "unsure". The Lanthony D-15 test is more sensitive and can be used to differentiate between participants with no colour vision deficiency ("pass") and participants with mild colour vision deficiency ("fail" or "unsure").

Apparatus

The task was performed on a single Colour Edge CG243W 24.1" Widescreen LCD display, which was linearized with an in-built sequence before each session. We used the Konica Minolta CS-100A chroma meter to measure the parameters of red, green, and blue guns of the monitor. The white point of the monitor was .319, .338, 94.2 in *Commission Internationale d'Eclairage (CIE) xyY* colour space. The gamma curves were estimated from luminance increments of each of the three guns using a standard protocol (Brainard et al., 2002). The measured primaries in *CIE xyY* of the monitor were Red = (.690, .306, 24.9), Green = (.185, .703, 60), and Blue = (.141, .027, 2.76). We used these measurements to convert colour values from the monitor-independent *CIE* xyY system to the monitor-dependent RGB system we needed to display them on screen. Viewing was unrestrained and the viewing distance was approximately 70 cm.

Supplemental Analyses and Results

Colour Vision Tests

Scores on all three colour blindness tests were used to evaluate the presence and the degree of colour blindness. Participants who passed two out of three tests were considered to have passed the colour vision tests in general. Participants who passed fewer than two of the three tests (i.e., received scores “fail” or “unsure” on two out of three tests) were considered to have failed the colour vision tests in general (see Table S 31).

We used a 2 x 2 independent-measures MANOVA to test whether colour-blind participants had different colour blindness test scores than non-colour-blind participants, and if there were differences between the two conditions. For these analyses, we included all participants (N = 129, $n_{\text{Colour-blind}}$ = 64, $n_{\text{Non-colour-blind}}$ = 65). The between-subjects independent variables were 1) self-reported colour blindness group (colour-blind vs. non-colour-blind) and 2) condition (colour term vs. colour patch). The dependent variables were 1) number of errors on Ishihara test, 2) number of crossing errors on Farnsworth D-15 test, 3) number of neighbour errors on Farnsworth D-15 test, 4) number of total errors on Farnsworth D-15 test, 5) number of crossing errors on Lanthony D-15 test, 6) number of neighbour errors on Lanthony D-15 test, and 7) number of total errors on Lanthony D-15 test.

The 2 x 2 MANOVA on the number of errors in colour blindness test scores was overall significant; Pillai’s Trace value = .89, $F(5, 121) = 198$, $p < .001$, $\eta_p^2 = .891$. The MANOVA revealed a significant main effect of self-reported study groups, Pillai’s Trace value = .82, $F(5, 121) = 114$, $p < .001$, $\eta_p^2 = .820$. The main effect of study group was present in all individual scores on the colour vision tests: 1) number of errors on Ishihara test, $F(1, 125) = 323$, $p < .001$, $\eta_p^2 = .721$, 2) number of crossing errors on Farnsworth D-15 test, $F(1, 125) =$

78.7, $p < .001$, $\eta_p^2 = .386$, 3) number of neighbour errors on Farnsworth D-15 test, $F(1, 125) = 21.3$, $p < .001$, $\eta_p^2 = .146$, 4) number of total errors on Farnsworth D-15 test, $F(1, 125) = 99.2$, $p < .001$, $\eta_p^2 = .443$, 5) number of crossing errors on Lanthony D-15 test, $F(1, 125) = 263$, $p < .001$, $\eta_p^2 = .678$, 6) number of neighbour errors on Lanthony D-15 test, $F(1, 125) = 24.6$, $p < .001$, $\eta_p^2 = .165$, and 7) number of total errors on Lanthony D-15 test, $F(1, 125) = 340$ $p < .001$, $\eta_p^2 = .731$. In all tests, self-reported colour-blind participants made significantly more errors than self-reported non-colour-blind participants (see Table S 31 for mean scores of each test).

As there was no main effect of condition, Pillai's Trace value = .02, $F(5, 121) = 0.35$, $p = .83$, $\eta_p^2 = .017$, we concluded that participant allocation to the conditions was random. The interaction between study group and condition was not significant either, Pillai's Trace value = .05, $F(5, 121) = 1.24$, $p = .29$, $\eta_p^2 = .049$, reinforcing the same conclusion.

Based on the re-categorisation, Table S 30 reports the number of participants included in re-categorised study groups. The same table also reports mean colour blindness index scores of both study groups in both conditions. Clearly, colour-blind participants had significantly higher colour blindness index scores than non-colour-blind participants, confirming their colour vision deficiency.

Emotion Intensity

Group-level analysis. The current study compares associations of colour blind and non-colour-blind participants. Consequently, we present emotion intensities split by colour for colour-blind participants (Table S 32) and non-colour-blind participants (Table S 33). We compared emotion associations between colour terms and colour patches. These comparisons revealed that colour-blind participants associated emotion concepts of higher intensity with *red*, *orange*, *yellow*, *pink*, *white*, and *black* as a term than as a patch (all $p_{FDR} < .046$). Similarly, non-colour-blind participants associated emotion concepts of higher intensity with *red* as a term than as a patch ($p_{FDR} = .004$). Non-colour-blind participants tended to associate more intense emotion concepts with *white* and *black* as a term than as a patch, which was nearly significant (both $p_{FDR} = .051$). Additionally, we present a comparison between colour-blind and non-colour-blind participants for emotion intensities split by colour. We present them separately for colour terms (Table S 34) and colour patches (Table S 35).

Individual-level analysis. We tested whether *emotion intensity* depended on the colour blindness index by fitting a linear regression model. The predictor variable was the colour blindness index and the outcome variable was average emotion intensity (across all colours and emotions). We further ran a series of analogous linear regression models per colour to test for the same dependence in each colour. We had to run 12 models per colour and not a single model with all the colours together due to missing data (see *Emotion intensity*). Again, all comparisons were FDR corrected (Benjamini & Hochberg, 1995). The linear regression model was not significant overall, $F(1, 127) = 1.08$, $p = .305$, *adjusted* $R^2 < .001$, indicating that the colour blindness index was not a significant predictor of average emotion intensity. Similarly, the colour blindness index was not a significant predictor of emotion intensity of any of the 12 colours, *p's* ≥ 0.055 (before correction).

Emotion dimensions

We derived emotion dimensions associated with colours from the number of emotion concepts associated with each colour. For valence, we counted how many positive and negative emotion concepts each participant associated with each colour. For arousal, we counted how many high arousal and low arousal emotion concepts each participant associated with each colour. For power, we counted how many high power and low power emotion concepts each participant associated with each colour (Table 1.1). The more emotions participants chose, the broader and less specific their colour-emotion associations were. The number of associated emotions varied from 0 to 10 for each level of valence (positive vs. negative), arousal (high vs. low arousal), and power (high vs. low power).

To compare emotion dimension associations between colour-blind and non-colour-blind participants, we conducted a mixed-design 2 x 2 x 2 x 12 multivariate analysis of variance (MANOVA) model. The three dependent variables were valence, arousal, and power. The independent variables were i) level of emotion dimensions (2 levels, positive – negative, high arousal – low arousal, or high power – low power); ii) study groups (2 levels, colour-blind or non-colour-blind); iii) conditions (2 levels, terms or patches); and iv) colour (12 levels, see *Colour Stimuli*). The interactions of interest were followed up with individual ANOVAs on each dependent variable and t-tests where appropriate. The main effects and interactions that did not concern study group were not further interpreted but could be visually deduced from Figure S 7. as well as inspected in the raw data.

A mixed-design MANOVA estimating the number of associated emotion concepts was overall significant; Pillai's Trace value = .70, $F(1, 131) = 230.6$, $p < .001$, $\eta_p^2 = .695$. However, the main effect of study group was not significant, Pillai's Trace value = .002, $F(1, 101) = 0.23$, $p = .630$, $\eta_p^2 = .002$, suggesting that colour-blind and non-colour-blind participants associated the same number of emotion concepts with all colours on average. The main effect of condition was not significant either, Pillai's Trace value = .000, $F(1, 101) = 0.34$, $p = .854$, $\eta_p^2 = .000$, suggesting that the same number of emotion concepts, on average, was associated with terms and patches. In contrast, the main effect of colour was significant, Pillai's Trace value = .50, $F(11, 91) = 8.32$, $p < .001$, $\eta_p^2 = .502$. The main effect of levels of emotion dimensions was also significant, Pillai's Trace value = .52, $F(3, 99) = 35.2$, $p < .001$, $\eta_p^2 = .516$. This result was further analysed for valence, arousal, and power separately.

The two-way interactions of interest were not significant. These interactions were between 1) study group and levels of emotion dimensions, Pillai's Trace value = .02, $F(3, 99) = 0.73$, $p = .539$, $\eta_p^2 = .022$, 2) study group and colour, Pillai's Trace value = .15, $F(11, 91) = 1.40$, $p = .188$, $\eta_p^2 = .145$, and 3) study group and condition, Pillai's Trace value = .02, $F(1, 101) = 1.79$, $p = .184$, $\eta_p^2 = .017$. Most of the three-way interactions of interest were also not significant. These interactions were between 1) study group, levels of emotion dimensions, and condition, Pillai's Trace value = .01, $F(3, 99) = 0.35$, $p = .788$, $\eta_p^2 = .011$, and 2) study group, colour, and condition, Pillai's Trace value = .05, $F(11, 91) = 0.46$, $p < .001$, $\eta_p^2 = .053$. The only significant three-way interaction of interest was between study group, levels of emotion dimensions, and colour, Pillai's Trace value = .44, $F(33, 69) = 1.63$, $p = .045$, $\eta_p^2 = .438$. This interaction was further analysed for valence, arousal, and power separately. The four-way interaction between study group, levels of emotion dimensions, colour, and condition was not significant, Pillai's Trace value = .42, $F(33, 69) = 1.53$, $p = .070$, $\eta_p^2 = .422$.

In contrast to the interactions of interest, the two-way and three-way interactions of lower interest were significant. These interactions were between 1) levels of emotion dimensions and condition, Pillai's Trace value = .10, F(3, 99) = 3.83, p = .012, η_p^2 = .104, 2) colour and condition, Pillai's Trace value = .27, F(11, 91) = 3.00, p = .002, η_p^2 = .266, 3) levels of emotion dimensions and colour, Pillai's Trace value = .871, F(33, 69) = 14.06, p < .001, η_p^2 = .871, and 4) levels of emotion dimensions, colour, and condition, Pillai's Trace value = .51, F(33, 69) = 2.21, p = .003, η_p^2 = .514. We did not further interpret these interactions, as they were not of interest to the current study. For visual representation of all results, see Figure S 7.

Valence. Following up the results of the mixed-design MANOVA with a mixed-design ANOVA on valence, there was the main effect of valence level, F(1, 101) = 107, p < .001, η_p^2 = .515, indicating a positivity bias. Participants overall associated more positive (M = 2.43, 95% CI = [2.13, 2.74]) than negative (M = 1.47, 95% CI = [1.24, 1.71]) emotion concepts with colours. This main effect was qualified by the interactions between valence level and colour, F(11, 1111) = 58.6, p < .001, η_p^2 = .367, valence level, colour, and condition, F(11, 1111) = 2.21, p = .012, η_p^2 = .021, and, most pertinent, valence level, colour, and study group, F(11, 1111) = 2.64, p = .002, η_p^2 = .025. We interpret the latter interaction below while the meaning of the two former interactions can be visually deduced from Figure S 7.

To break-down the interaction between valence level, colour, and study group, we performed 12 2 x 2 x 2 ANOVA models, one per colour, with valence level (positive vs. negative) and study group (colour-blind vs. non-colour-blind) as independent variables. The main effect of study group was only significant for *red*, F(1,103) = 4.47, p = .037, η_p^2 = .042. That is, colour-blind participants associated fewer emotion concepts with *red* than non-colour-blind participants, irrespective of whether *red* was a term or a patch. The main effects of study group for other colours were not significant (ps ≥ .328). The interaction between study group and condition was significant for *turquoise*, F(1,103) = 7.98, p = .006, η_p^2 = .072, *purple*, F(1,103) = 8.40, p = .005, η_p^2 = .075, and *pink*, F(1,103) = 4.00, p = .048, η_p^2 = .037. Further series of paired-samples t-tests showed that colour-blind participants associated more positive than negative emotion concepts with *turquoise* (p_{FDR} < .001) and *pink* (p_{FDR} < .001) but not with *purple* (p_{FDR} = .826). In contrast, non-colour-blind participants associated more positive than negative emotion concepts with *turquoise* (p_{FDR} < .001), *pink* (p_{FDR} < .001), and *purple* (p_{FDR} < .001). Thus, at the core of this interaction was valence of *purple* – non-colour-blind participants evaluated *purple* as a positive colour while colour-blind participants evaluated *purple* as an ambivalent colour.

Arousal. Following up on the results of the mixed-design MANOVA with a mixed-design ANOVA on arousal, there was no main effect of arousal level, $F(1, 101) = 1.63$, $p = .204$, $\eta_p^2 = .016$. There were significant two-way and three-way interactions but none of them included study group. These interactions were between 1) arousal level and condition, $F(1, 101) = 11.3$, $p = .001$, $\eta_p^2 = .101$, 2) arousal level and colour, $F(11, 1111) = 45.0$, $p < .001$, $\eta_p^2 = .308$, and 3) arousal level, colour, and condition, $F(11, 1111) = 4.18$, $p < .001$, $\eta_p^2 = .040$. Since these interactions were not of interest, their meaning can be visually deduced from Figure S 7. A&C.

Power. Following up on the results of the mixed-design MANOVA with a mixed-design ANOVA on power, there was the main effect of power level, $F(1, 101) = 4.23$, $p = .042$, $\eta_p^2 = .040$. Participants overall associated slightly more high power ($M = 2.00$, *95% CI* = [1.74, 2.27]) than lower power ($M = 1.90$, *95% CI* = [1.65, 2.16]) emotion concepts with colours. The only significant interaction was between power level and colour, $F(11, 1111) = 19.1$, $p < .001$, $\eta_p^2 = .159$. Since it was not of interest, we did not further interpret this interaction and its meaning can be visually deduced from Figure S 7. B&D.

Colour Naming

We compared colour naming between colour-blind and non-colour-blind participants in the patches condition. We present the average likelihood mean values that each colour patch was named using each colour name in Table S 40 for colour-blind and Table S 41 for non-colour-blind participants. The responses of colour-blind participants were highly correlated to the responses of non-colour-blind participants, $r = .943$, $p < .001$.

Supplemental Figures

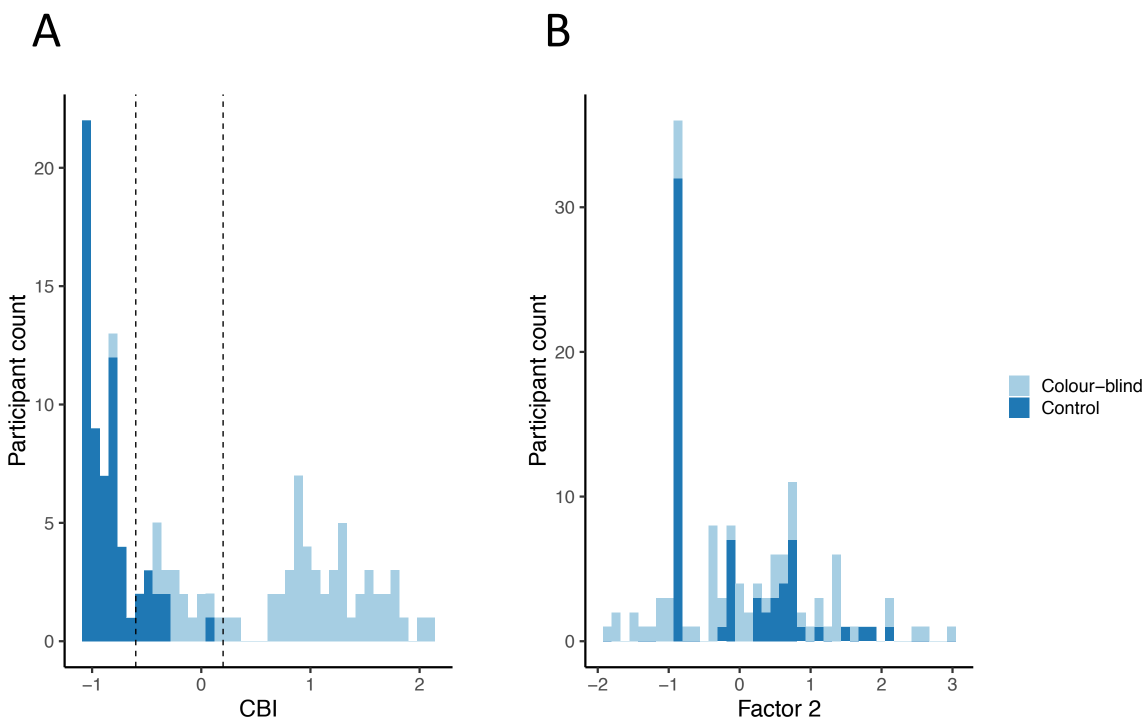

Figure S 6. Solutions of the principal component analysis, separated by self-identified study group.

(A) Colour blindness index (CBI), dotted lines indicate the separation of participants into re-categorised colour-blind participants (to the right of the rightward line at 0.2) and re-categorised non-colour-blind participants (i.e., control, to the left of the leftward line at -0.6). (B) Factor 2 of the factor analysis, which clearly does not separate colour-blind and non-colour-blind participants. Thus, the latter measure was not considered for our further analyses. See Table S 29 for factor loadings.

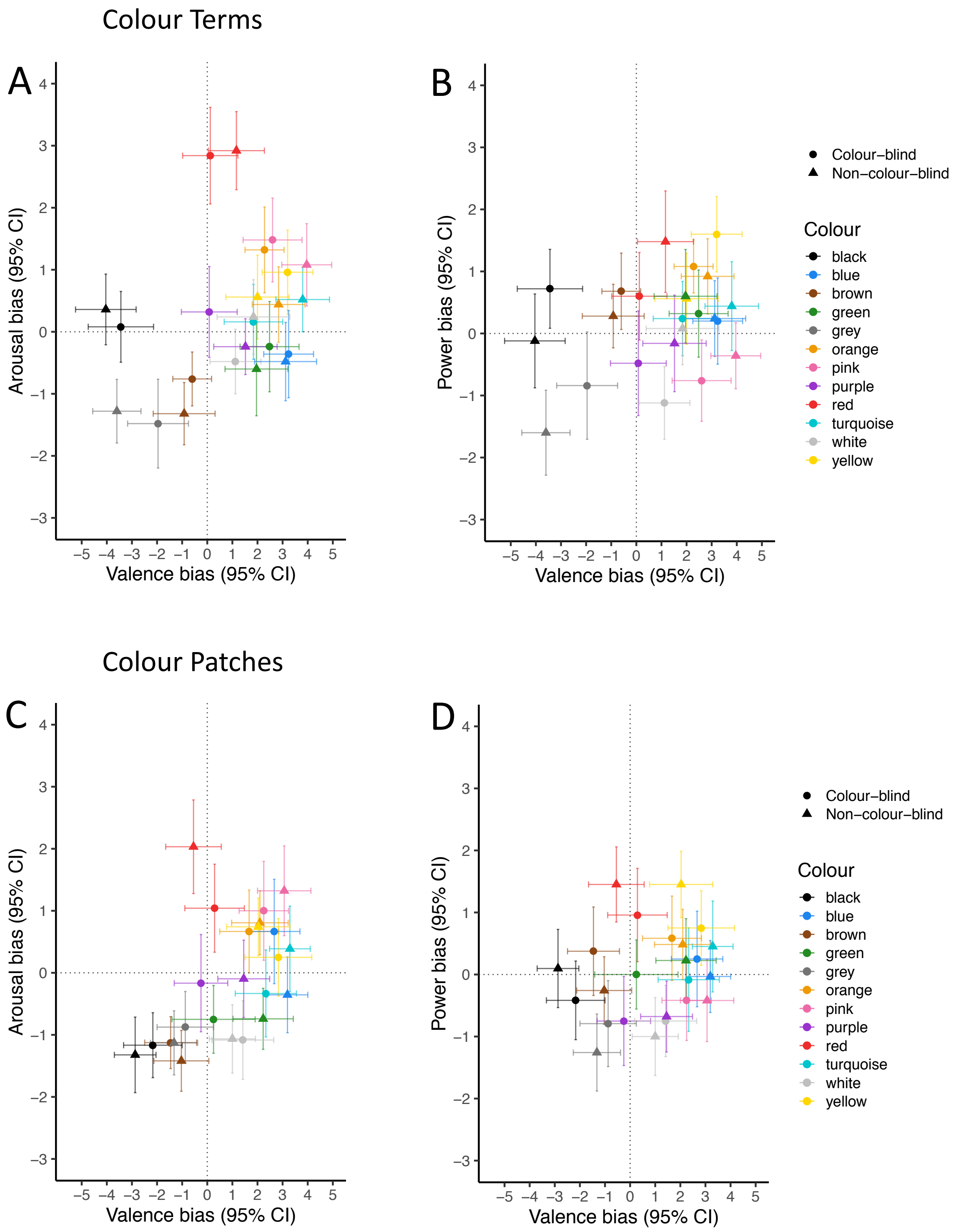

Figure S 7. Valence, arousal, and power biases of colour, separated by colour-blind participants (circles) and non-colour-blind participants (triangles).

(A & C) Colour terms (A) or colour patches (C) positioned on the valence x arousal space. (continues onto the next page)

Valence bias was calculated by subtracting the number of negative emotion concepts from the number of positive emotion concepts associated with each colour (positive – negative); higher values indicate a more positive evaluation. Arousal bias calculated by subtracting the number of low arousal emotion concepts from the number of high arousal emotion concepts associated with each colour (high arousal – low arousal); higher values indicate a more arousing evaluation. (B & D) Colour terms (B) or colour patches (D) positioned on the valence x power space. Power bias calculated by subtracting weak emotion concepts from strong emotion concepts associated with each colour (strong – weak); higher values indicate a more empowering evaluation. (A & B) Error bars indicate 95% confidence intervals (*CI*) of the mean. Dotted lines indicate the separation between positive-negative, high arousal-low arousal, and strong-weak emotion concepts. Colours are for visualisation purposes only.

Supplemental Tables

Table S 29. Item-loadings on the two factors.

The first factor was identified as Colour Blindness Index while the second factor was difficult to interpret and was left unnamed.

Item	**Colour blindness index (Factor 1)**	**Factor 2**
Ishihara errors	.900	-.082
Farnsworth D-15 crossing errors	.846	-.326
Farnsworth D-15 neighbour errors	.533	.483
Lanthony D-15 crossing errors	.948	-.152
Lanthony D-15 neighbour errors	.283	.835

Table S 30. Participants re-categorised as colour-blind or non-colour-blind based on their Colour Blindness Index score.

These participants were included in group-level analyses. Superscript letters (^{a,b}) indicate significant differences at $p < .001$.

		N	Colour blindness index	
			Mean	*SD*
Colour terms condition	Colour blind	25	1.20^{a}	0.43
	Non-colour-blind	25	-0.93^{a}	0.10
Colour patches condition	Colour blind	24	1.17^{b}	0.41
	Non-colour-blind	31	-0.92^{b}	0.11

Table S 31. Colour blindness test results of the colour-blind and non-colour-blind participants.

Participants passed colour blindness tests in general if they passed at least two out of three colour blindness tests (*Final decision*). Passing criteria for each individual test and how errors were counted appear in text.

		Ishihara test				**Farnsworth D-15 test**						**Lanthony D-15 test**						**Final decision**	
		Pass (*n*; %)	Fail (*n*; %)	Unsure (*n*; %)	No. errors (*M, SD, range*)	Pass (*n*; %)	Fail (*n*; %)	Unsure (*n*; %)	No. cross-ing errors (*M, SD, range*)	No. neigh-bour errors (*M, SD, range*)	No. total errors (*M, SD, range*)	Pass (*n*; %)	Fail (*n*; %)	Unsure (*n*; %)	No. cross-ing errors (*M, SD, range*)	No. neigh-bour errors (*M, SD, range*)	No. total errors (*M, SD, range*)	Pass (*n*; %)	Fail (*n*; %)
Colour terms condition	**Colour-blind**	0 (0.0)	27 (90.0)	3 (10.0)	7.3 (2.8), 2-11	8 (26.7)	19 (63.3)	3 (10.0)	4.9 (3.7), 0-11	1.5 (1.6), 0-6	6.4 (4.0), 0-12	2 (6.7)	27 (90.0)	1 (3.3)	6.23 (2.7), 0-10	3.0 (1.7), 0-6	9.2 (1.8), 4-12	2 (6.7)	28 (93.3)
	Non colour-blind	31 (100)	0 (0.0)	0 (0.0)	0.2 (0.4), 0-1	31 (100)	0 (0.0)	0 (0.0)	0.0 (0.0), 0	0.6 (1.4), 0-5	0.6 (1.4), 0-5	26 (83.9)	2 (6.5)	3 (9.7)	0.3 (0.8), 0-3	1.7 (1.9), 0-6	2.0 (2.3), 0-7	31 (100)	0 (0.0)
Colour patches condition	**Colour-blind**	0 (0.0)	26 (76.5)	8 (23.5)	6.2 (2.9), 2-10	14 (41.2)	17 (50.0)	3 (8.8)	3.7 (3.9), 0-12	1.7 (1.8), 0-7	5.4 (4.3), 0-14	1 (2.9)	27 (79.4)	6 (17.6)	5.6 (2.8), 0-10	3.3 (2.0), 0-8	8.9 (2.8), 0-13	1 (2.9)	33 (97.1)
	Non colour-blind	32 (94.1)	0 (0.0)	2 (5.9)	0.4 (0.6), 0-2	33 (97.1)	1 (2.9)	0 (0.0)	0.1 (0.5), 0-3	0.3 (0.5), 0-2	0.4 (1.0), 0-5	31 (91.2)	0 (0.0)	3 (8.8)	0.1 (0.4), 0-2	1.4 (1.8), 0-7	1.5 (1.9), 0-7	34 (100)	0 (0.0)

Table S 32. Descriptive values of the intensity of the associated emotion concepts with colour terms and colour patches by colour-blind participants.

Significant differences, after the FDR correction, in emotion intensity between the two conditions are flagged as * p_{FDR} < .050, ** p_{FDR} < .010.

	Colour terms			Colour patches					
Colour blind	*M*	95% *CI*	Range	*M*	95% *CI*	Range	*N*	*t*-value	Cohen's *d*
Red	4.17	[3.88,4.46]	3.00-5.00	3.18	[2.73,3.62]	1.33-4.67	47	3.96**	1.16
Orange	3.73	[3.40,4.07]	2.00-5.00	2.87	[2.46,3.27]	1.00-4.67	47	3.41**	1.00
Yellow	3.99	[3.72,4.27]	2.26-5.00	3.39	[2.96,3.81]	1.67-5.00	49	2.50*	0.71
Green	3.76	[3.43,4.08]	1.75-5.00	3.29	[2.94,3.64]	1.50-5.00	45	2.04	0.61
Turquoise	3.43	[3.14,3.73]	2.50-5.00	3.25	[2.83,3.66]	1.33-4.67	43	0.75	0.23
Blue	3.80	[3.54,4.06]	2.67-4.50	3.51	[3.14,3.87]	1.30-5.00	48	1.36	0.39
Purple	3.44	[3.03,3.84]	2.00-5.00	2.95	[2.45,3.44]	1.60-5.00	44	1.61	0.48
Pink	3.61	[3.27,3.95]	2.00-5.00	2.85	[2.34,3.36]	1.00-4.67	45	2.61*	0.78
Brown	3.17	[2.68,3.66]	1.71-5.00	3.13	[2.71,3.55]	1.25-5.00	42	0.13	0.04
White	3.78	[3.27,4.29]	2.00-5.00	3.10	[2.76,3.45]	1.75-5.00	43	2.33*	0.71
Grey	3.42	[3.08,3.77]	1.92-5.00	2.92	[2.48,3.36]	1.63-5.00	44	1.91	0.58
Black	3.87	[3.49,4.25]	1.80-5.00	2.99	[2.53,3.46]	1.00-5.00	46	3.03*	0.89
Overall	3.71	[3.52,3.91]	2.68-4.64	3.16	[2.86,3.45]	1.78-4.54	49	3.26**	0.93

Table S 33. Descriptive values of the intensity of the associated emotion concepts with colour terms and colour patches by non-colour-blind participants.

Significant differences, after the FDR correction, in emotion intensity between the two conditions are flagged as *** $p_{FDR} < .001$, ∽ $p_{FDR} = .051$

	Colour terms			Colour patches					
Non-colour-blind	*M*	95% *CI*	Range	*M*	95% *CI*	Range	*N*	*t*-value	Cohen's *d*
Red	3.95	[3.65,4.25]	2.69-5.00	3.16	[2.87,3.45]	1.11-5.00	56	3.87***	1.04
Orange	3.19	[2.87,3.51]	2.00-4.50	3.10	[2.75,3.45]	1.00-5.00	53	0.37	0.10
Yellow	3.46	[3.14,3.78]	2.00-4.50	3.40	[2.92,3.87]	1.00-5.00	52	0.22	0.06
Green	3.38	[3.02,3.74]	1.50-5.00	2.94	[2.66,3.22]	1.67-5.00	56	2.02	0.54
Turquoise	3.43	[3.03,3.82]	1.00-5.00	3.27	[2.91,3.63]	1.00-5.00	54	0.59	0.16
Blue	3.49	[3.14,3.84]	2.00-4.67	3.02	[2.68,3.37]	1.25-5.00	56	1.93	0.52
Purple	3.02	[2.65,3.38]	1.43-4.67	3.16	[2.77,3.54]	1.33-5.00	54	-0.53	0.15
Pink	3.41	[3.05,3.77]	2.00-5.00	3.04	[2.68,3.39]	1.00-5.00	54	1.50	0.41
Brown	2.73	[2.29,3.17]	1.00-4.33	2.85	[2.47,3.23]	1.00-4.50	50	-0.42	0.12
White	3.91	[3.42,4.40]	2.00-5.00	3.03	[2.56,3.50]	1.00-5.00	47	2.68∽	0.78
Grey	3.47	[3.09,3.85]	1.00-5.00	2.94	[2.50,3.38]	1.00-5.00	50	1.84	0.52
Black	3.48	[3.14,3.82]	2.13-5.00	2.81	[2.44,3.19]	1.00-5.00	55	2.61∽	0.71
Overall	3.45	[3.24,3.67]	2.50-4.26	3.09	[2.82,3.35]	1.64-4.65	56	2.15	0.58

Table S 34. Descriptive values of the intensity of the associated emotion concepts by colour-blind and non-colour-blind participants with colour terms.

Significant differences, after the FDR correction, in emotion intensity between the study groups are flagged as * $p_{FDR} < .050$, ** $p_{FDR} < .010$, *** $p_{FDR} < .001$, yet, no comparison was significant.

	Colour blind			Non-colour-blind					
Colour terms	*M*	95% *CI*	Range	*M*	95% *CI*	Range	*N*	*t*-value	Cohen's *d*
Red	4.17	[3.88,4.46]	3.00-5.00	3.95	[3.65,4.25]	2.69-5.00	50	1.09	0.31
Orange	3.73	[3.40,4.07]	2.00-5.00	3.19	[2.87,3.51]	2.00-4.50	47	2.43	0.71
Yellow	3.99	[3.72,4.27]	2.26-5.00	3.46	[3.14,3.78]	2.00-4.50	49	2.63	0.75
Green	3.76	[3.43,4.08]	1.75-5.00	3.38	[3.02,3.74]	1.50-5.00	47	1.59	0.46
Turquoise	3.43	[3.14,3.73]	2.50-5.00	3.43	[3.03,3.82]	1.00-5.00	44	0.02	0.01
Blue	3.80	[3.54,4.06]	2.67-4.50	3.49	[3.14,3.84]	2.00-4.67	49	1.46	0.42
Purple	3.44	[3.03,3.84]	2.00-5.00	3.02	[2.65,3.38]	1.43-4.67	46	1.61	0.47
Pink	3.61	[3.27,3.95]	2.00-5.00	3.41	[3.05,3.77]	2.00-5.00	48	0.85	0.25
Brown	3.17	[2.68,3.66]	1.71-5.00	2.73	[2.29,3.17]	1.00-4.33	40	1.41	0.45
White	3.78	[3.27,4.29]	2.00-5.00	3.91	[3.42,4.40]	2.00-5.00	44	-0.38	0.11
Grey	3.42	[3.08,3.77]	1.92-5.00	3.47	[3.09,3.85]	1.00-5.00	47	-0.19	0.06
Black	3.87	[3.49,4.25]	1.80-5.00	3.48	[3.14,3.82]	2.13-5.00	48	1.57	0.45
Overall	3.71	[3.52,3.91]	2.68-4.64	3.45	[3.24,3.67]	2.50-4.26	50	1.83	0.52

Table S 35. Descriptive values of the intensity of the associated emotion concepts by colour-blind and non-colour-blind participants with colour patches.

Significant differences, after the FDR correction, in emotion intensity between the study groups are flagged as * p_{FDR} < .050, ** p_{FDR} < .010, *** p_{FDR} < .001, yet, no comparison was significant.

	Colour-blind			Non-colour-blind					
Colour patches	*M*	95% *CI*	Range	*M*	95% *CI*	Range	*N*	*t*-value	Cohen's *d*
Red	3.18	[2.73,3.62]	1.33-4.67	3.16	[2.87,3.45]	1.11-5.00	53	0.08	0.02
Orange	2.87	[2.46,3.27]	1.00-4.67	3.10	[2.75,3.45]	1.00-5.00	53	-0.89	0.25
Yellow	3.39	[2.96,3.81]	1.67-5.00	3.40	[2.92,3.87]	1.00-5.00	52	-0.03	0.01
Green	3.29	[2.94,3.64]	1.50-5.00	2.94	[2.66,3.22]	1.67-5.00	54	1.61	0.44
Turquoise	3.25	[2.83,3.66]	1.33-4.67	3.27	[2.91,3.63]	1.00-5.00	53	-0.11	0.03
Blue	3.51	[3.14,3.87]	1.30-5.00	3.02	[2.68,3.37]	1.25-5.00	55	1.95	0.53
Purple	2.95	[2.45,3.44]	1.60-5.00	3.16	[2.77,3.54]	1.33-5.00	52	-0.71	0.20
Pink	2.85	[2.34,3.36]	1.00-4.67	3.04	[2.68,3.39]	1.00-5.00	51	-0.64	0.18
Brown	3.13	[2.71,3.55]	1.25-5.00	2.85	[2.47,3.23]	1.00-4.50	52	1.03	0.29
White	3.10	[2.76,3.45]	1.75-5.00	3.03	[2.56,3.50]	1.00-5.00	46	0.25	0.07
Grey	2.92	[2.48,3.36]	1.63-5.00	2.94	[2.50,3.38]	1.00-5.00	47	-0.07	0.02
Black	2.99	[2.53,3.46]	1.00-5.00	2.81	[2.44,3.19]	1.00-5.00	53	0.62	0.17
Overall	3.16	[2.86,3.45]	1.78-4.54	3.09	[2.82,3.35]	1.64-4.65	55	0.36	0.10

Table S 36. Colour-emotion association matrix with the proportion of participants who associate given colours with given emotions.

These proportions were derived from colour-emotion associations of colour-blind participants with colour terms.

	Red	Orange	Yellow	Green	Turquoise	Blue	Purple	Pink	Brown	Grey	White	Black
Interest	0.00	0.08	0.24	0.32	0.24	0.48	0.12	0.04	0.04	0.16	0.12	0.20
Amusement	0.12	0.44	0.48	0.40	0.36	0.36	0.24	0.40	0.00	0.08	0.00	0.00
Pride	0.12	0.16	0.44	0.12	0.16	0.24	0.08	0.08	0.16	0.08	0.12	0.16
Joy	0.20	0.64	0.76	0.44	0.28	0.36	0.24	0.32	0.04	0.04	0.24	0.04
Pleasure	0.40	0.52	0.72	0.32	0.44	0.44	0.32	0.40	0.08	0.04	0.20	0.04
Contentment	0.08	0.28	0.32	0.32	0.20	0.40	0.12	0.12	0.08	0.08	0.36	0.00
Admiration	0.28	0.24	0.32	0.16	0.16	0.28	0.16	0.36	0.04	0.08	0.24	0.04
Love	0.72	0.16	0.16	0.20	0.12	0.20	0.12	0.68	0.04	0.04	0.12	0.00
Relief	0.00	0.12	0.24	0.44	0.36	0.44	0.12	0.20	0.08	0.08	0.40	0.00
Compassion	0.20	0.16	0.20	0.28	0.16	0.24	0.12	0.44	0.00	0.20	0.28	0.00
Sadness	0.00	0.08	0.04	0.08	0.08	0.12	0.32	0.04	0.00	0.60	0.12	0.52
Guilt	0.08	0.08	0.04	0.00	0.12	0.00	0.24	0.08	0.00	0.20	0.16	0.32
Regret	0.04	0.00	0.08	0.00	0.12	0.04	0.28	0.04	0.04	0.40	0.16	0.40
Shame	0.28	0.00	0.04	0.08	0.04	0.00	0.20	0.12	0.12	0.16	0.12	0.36
Disappointment	0.08	0.00	0.04	0.04	0.08	0.00	0.16	0.04	0.12	0.44	0.12	0.20
Fear	0.16	0.08	0.04	0.04	0.12	0.00	0.12	0.04	0.08	0.20	0.12	0.48
Disgust	0.04	0.08	0.12	0.24	0.04	0.04	0.04	0.00	0.48	0.20	0.04	0.28
Contempt	0.08	0.04	0.08	0.04	0.04	0.00	0.08	0.00	0.24	0.36	0.04	0.40
Hate	0.52	0.04	0.08	0.00	0.00	0.00	0.00	0.04	0.04	0.24	0.04	0.48
Anger	0.72	0.12	0.12	0.00	0.00	0.00	0.12	0.04	0.04	0.04	0.04	0.48

Table S 37. Colour-emotion association matrix with the proportion of participants who associate given colours with given emotions.

These proportions were derived from colour-emotion associations of non-colour-blind participants with colour terms.

	Red	Orange	Yellow	Green	Turquoise	Blue	Purple	Pink	Brown	Grey	White	Black
Interest	0.36	0.32	0.28	0.24	0.32	0.52	0.32	0.20	0.28	0.04	0.28	0.04
Amusement	0.32	0.48	0.60	0.32	0.36	0.44	0.28	0.36	0.08	0.00	0.08	0.04
Pride	0.36	0.36	0.32	0.32	0.28	0.32	0.32	0.20	0.12	0.04	0.32	0.12
Joy	0.52	0.44	0.52	0.36	0.68	0.32	0.28	0.64	0.04	0.00	0.32	0.00
Pleasure	0.68	0.56	0.48	0.40	0.56	0.48	0.28	0.72	0.08	0.00	0.32	0.00
Contentment	0.16	0.40	0.36	0.40	0.44	0.44	0.28	0.32	0.24	0.00	0.24	0.00
Admiration	0.28	0.20	0.40	0.24	0.44	0.36	0.16	0.32	0.08	0.00	0.40	0.12
Love	0.88	0.20	0.12	0.16	0.20	0.16	0.52	0.84	0.00	0.00	0.24	0.08
Relief	0.04	0.20	0.20	0.28	0.40	0.48	0.20	0.28	0.00	0.08	0.36	0.08
Compassion	0.28	0.28	0.20	0.24	0.20	0.24	0.36	0.52	0.12	0.12	0.16	0.04
Sadness	0.12	0.04	0.12	0.04	0.04	0.20	0.20	0.04	0.12	0.76	0.16	0.60
Guilt	0.28	0.08	0.20	0.04	0.00	0.04	0.08	0.00	0.08	0.36	0.08	0.40
Regret	0.24	0.04	0.16	0.16	0.00	0.12	0.16	0.16	0.20	0.56	0.08	0.44
Shame	0.24	0.12	0.28	0.08	0.00	0.00	0.20	0.04	0.28	0.32	0.00	0.44
Disappointment	0.04	0.00	0.16	0.04	0.04	0.04	0.16	0.08	0.24	0.68	0.04	0.40
Fear	0.20	0.04	0.04	0.04	0.00	0.12	0.24	0.00	0.12	0.40	0.28	0.72
Disgust	0.08	0.12	0.24	0.32	0.00	0.00	0.20	0.04	0.56	0.12	0.00	0.28
Contempt	0.16	0.04	0.16	0.24	0.00	0.08	0.16	0.04	0.28	0.32	0.04	0.36
Hate	0.60	0.00	0.08	0.04	0.00	0.00	0.00	0.04	0.04	0.20	0.16	0.52
Anger	0.76	0.12	0.04	0.00	0.00	0.04	0.08	0.00	0.04	0.16	0.04	0.40

Table S 38. Colour-emotion association matrix with the proportion of participants who associate given colours with given emotions.

These proportions were derived from colour-emotion associations of colour-blind participants with colour patches.

	Red	Orange	Yellow	Green	Turquoise	Blue	Purple	Pink	Brown	Grey	White	Black
Interest	0.21	0.29	0.42	0.33	0.38	0.29	0.21	0.08	0.25	0.21	0.33	0.21
Amusement	0.21	0.42	0.50	0.25	0.33	0.29	0.08	0.38	0.04	0.08	0.13	0.04
Pride	0.25	0.21	0.29	0.21	0.33	0.17	0.17	0.13	0.08	0.08	0.25	0.08
Joy	0.17	0.46	0.63	0.33	0.46	0.50	0.13	0.46	0.04	0.08	0.21	0.04
Pleasure	0.38	0.42	0.33	0.25	0.50	0.67	0.21	0.38	0.04	0.08	0.13	0.04
Contentment	0.17	0.25	0.50	0.21	0.46	0.29	0.13	0.38	0.13	0.13	0.29	0.13
Admiration	0.13	0.33	0.42	0.17	0.33	0.42	0.13	0.38	0.13	0.13	0.25	0.08
Love	0.46	0.08	0.17	0.08	0.13	0.25	0.29	0.54	0.13	0.21	0.17	0.08
Relief	0.17	0.21	0.21	0.33	0.42	0.33	0.08	0.21	0.13	0.13	0.54	0.04
Compassion	0.21	0.17	0.25	0.13	0.21	0.29	0.33	0.33	0.17	0.17	0.25	0.04
Sadness	0.13	0.08	0.13	0.21	0.21	0.13	0.25	0.13	0.13	0.33	0.25	0.42
Guilt	0.13	0.08	0.04	0.25	0.21	0.08	0.38	0.08	0.17	0.21	0.13	0.21
Regret	0.17	0.13	0.08	0.29	0.21	0.08	0.25	0.04	0.25	0.29	0.13	0.38
Shame	0.08	0.25	0.04	0.25	0.08	0.08	0.21	0.13	0.25	0.17	0.04	0.21
Disappointment	0.08	0.13	0.08	0.25	0.17	0.08	0.21	0.13	0.21	0.38	0.17	0.50
Fear	0.25	0.04	0.13	0.08	0.08	0.13	0.13	0.13	0.08	0.13	0.17	0.25
Disgust	0.17	0.13	0.08	0.33	0.08	0.08	0.13	0.13	0.71	0.21	0.13	0.33
Contempt	0.13	0.08	0.13	0.25	0.08	0.08	0.21	0.08	0.38	0.25	0.04	0.33
Hate	0.38	0.08	0.08	0.04	0.04	0.04	0.17	0.13	0.25	0.13	0.04	0.17
Anger	0.54	0.17	0.08	0.08	0.04	0.04	0.08	0.04	0.17	0.08	0.04	0.17

Table S 39. Colour-emotion association matrix with the proportion of participants who associate given colours with given emotions.

These proportions were derived from colour-emotion associations of non-colour-blind participants with colour patches.

	Red	Orange	Yellow	Green	Turquoise	Blue	Purple	Pink	Brown	Grey	White	Black
Interest	0.06	0.06	0.26	0.55	0.32	0.48	0.10	0.13	0.19	0.10	0.23	0.10
Amusement	0.19	0.35	0.48	0.19	0.48	0.32	0.26	0.48	0.00	0.03	0.06	0.00
Pride	0.26	0.29	0.26	0.23	0.26	0.29	0.16	0.03	0.06	0.06	0.06	0.03
Joy	0.19	0.52	0.55	0.35	0.58	0.42	0.26	0.42	0.06	0.06	0.16	0.03
Pleasure	0.39	0.35	0.42	0.42	0.52	0.48	0.26	0.61	0.13	0.06	0.10	0.00
Contentment	0.03	0.35	0.29	0.48	0.48	0.42	0.29	0.23	0.16	0.13	0.26	0.03
Admiration	0.23	0.29	0.29	0.26	0.29	0.35	0.23	0.23	0.10	0.03	0.19	0.03
Love	0.55	0.16	0.06	0.13	0.19	0.19	0.32	0.74	0.00	0.03	0.03	0.00
Relief	0.06	0.16	0.13	0.35	0.32	0.42	0.26	0.26	0.16	0.23	0.55	0.10
Compassion	0.16	0.26	0.10	0.16	0.13	0.26	0.29	0.45	0.10	0.10	0.16	0.06
Sadness	0.06	0.03	0.06	0.10	0.03	0.16	0.16	0.06	0.16	0.45	0.16	0.35
Guilt	0.19	0.13	0.10	0.13	0.06	0.06	0.13	0.10	0.16	0.23	0.03	0.32
Regret	0.13	0.03	0.03	0.13	0.16	0.16	0.13	0.13	0.29	0.39	0.23	0.32
Shame	0.19	0.06	0.00	0.06	0.00	0.00	0.13	0.03	0.16	0.16	0.03	0.13
Disappointment	0.06	0.03	0.03	0.10	0.03	0.03	0.10	0.03	0.32	0.39	0.16	0.42
Fear	0.19	0.10	0.10	0.00	0.00	0.03	0.03	0.03	0.03	0.26	0.10	0.35
Disgust	0.23	0.03	0.13	0.26	0.00	0.00	0.13	0.03	0.52	0.13	0.03	0.55
Contempt	0.32	0.10	0.16	0.03	0.00	0.00	0.13	0.03	0.23	0.10	0.00	0.52
Hate	0.61	0.06	0.10	0.03	0.00	0.00	0.00	0.00	0.10	0.03	0.00	0.16
Anger	0.68	0.13	0.10	0.06	0.00	0.00	0.03	0.06	0.03	0.03	0.06	0.13

Table S 40. Confusion matrix for the colour-naming task.

The columns represent colour patches that were given to the self-reported colour-blind participants (*n* = 22). The rows represent colour terms given to participants. The numbers represent mean evaluation of the likelihood that each colour patch would be named with each colour term (0-100). The values in bold mark the most likely colour term per colour patch.

		Presented colour patch											
		Black	Blue	Brown	Green	Grey	Orange	Pink	Purple	Red	Turquoise	White	Yellow
	Black	25.03	0.25	1.04	0.33	0.39	0.22	0.42	0.43	0.23	0.49	0.18	0.06
	Blue	1.10	**93.78**	0.21	0.20	15.53	0.16	9.48	21.74	0.35	**86.14**	1.19	0.20
Evaluated colour term	Brown	44.83	0.04	**82.31**	6.86	0.22	5.77	0.10	0.06	5.70	0.30	0.12	0.23
	Green	**71.32**	0.11	32.48	**91.85**	8.78	4.15	1.34	0.46	1.22	13.61	0.24	5.58
	Grey	20.61	0.95	1.85	0.41	**90.13**	0.04	28.00	3.44	0.21	15.69	7.70	0.17
	Orange	0.40	0.20	10.90	4.17	0.16	**94.65**	0.42	0.43	12.04	0.19	0.35	19.34
	Pink	0.82	7.54	0.12	0.13	33.01	2.01	**91.31**	50.78	26.38	8.83	6.73	0.08
	Purple	0.05	13.98	0.44	0.25	4.39	0.15	9.68	**81.00**	3.28	9.86	0.17	0.10
	Red	1.71	0.28	10.98	0.18	2.47	11.86	5.99	5.98	**93.98**	0.82	0.41	1.58
	Turquoise	3.99	49.02	1.12	0.92	26.98	0.37	11.70	21.51	4.30	65.37	0.73	1.08
	White	0.25	0.93	0.05	0.18	10.17	0.13	10.71	0.25	0.17	5.51	**94.51**	0.06
	Yellow	0.11	0.34	4.02	4.94	0.53	21.25	0.16	0.08	1.49	0.15	0.98	**93.53**

Table S 41. Confusion matrix for the colour-naming task.

The columns represent colour patches that were given to the self-reported non-colour-blind participants (*n* = 33). The rows represent colour terms give to participants. The numbers represent mean evaluation of the likelihood that each colour patch would be named with each colour term (0-100). The values in bold mark the most likely colour term per colour patch; several values are marked if they have similar likelihood.

		Presented colour patch											
		Black	Blue	Brown	Green	Grey	Orange	Pink	Purple	Red	Turquoise	White	Yellow
	Black	**49.97**	0.27	1.01	0.05	3.03	0.05	0.43	0.20	0.11	0.20	0.12	0.19
	Blue	2.32	**97.17**	0.48	1.36	9.73	0.57	0.09	0.84	0.16	**92.41**	0.11	1.33
Evaluated colour term	Brown	12.04	0.61	**96.55**	0.42	3.31	5.94	0.52	0.78	0.47	0.05	0.14	0.55
	Green	**38.54**	1.50	1.28	**99.29**	1.13	0.58	0.05	0.26	0.04	2.79	0.04	0.15
	Grey	**45.31**	1.10	0.56	1.13	**97.42**	0.07	0.11	0.64	0.29	0.80	9.73	0.42
	Orange	0.05	0.29	12.45	0.12	0.10	**92.65**	0.49	0.12	10.22	0.16	0.21	3.73
	Pink	0.18	0.34	0.10	0.67	0.37	1.13	**98.88**	10.42	18.07	1.69	0.53	0.58
	Purple	0.63	1.76	0.62	0.11	1.56	0.19	15.55	**99.24**	0.67	0.27	0.29	0.43
	Red	0.63	0.08	3.24	0.38	0.08	3.26	10.28	3.47	**97.26**	0.86	0.13	1.57
	Turquoise	2.58	54.46	0.23	1.77	2.72	0.51	2.15	3.66	0.19	**82.57**	0.20	0.03
	White	0.04	1.19	0.48	0.04	16.81	0.08	2.85	0.06	0.24	1.03	**99.69**	0.19
	Yellow	0.28	0.42	6.41	0.58	0.34	25.59	0.32	0.13	0.64	0.26	0.27	**99.89**

Chapter 6

Universality in The Domains of Colour and Emotion

Colour-Emotion Associations

In Chapter 2, we concluded that colour-emotion associations were highly comparable across the 30 nations and could be considered another human psychological universal. The same conclusion of universality has been reached in several other previous studies (Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Ou et al., 2018; Specker et al., 2018). Universal conceptual associations have also been reported for diverse conceptual associations with colours, including but not limited to associations with emotions (Tham et al., 2019). D. R. Simmons and Asher (2010) even proposed four universal factors influencing emotional responses to colour. The four factors were related to i) arousal of reddish colours, ii) pleasantness of saturated colours, iii) aversion to yellow, green, and brown, and iv) affinity to sunny yellows.

However, not all previous studies claimed universality. Other studies rather highlighted differences in colour-emotion associations (Barchard et al., 2017; Hupka et al., 1997; Madden et al., 2000). Indeed, the reported similarity in the pattern of colour-emotion associations was not at 100%, which leaves scope for nation-specific colour-emotion associations. Such nation-specific associations could partly be accounted for by differences in languages and/or geographical locations of participants (see results of Chapters 2 and 4). Differences between studies could also be potentially explained by differences in methodologies. Colour-emotion associations can be analysed in terms of *which* emotions are associated, as compared to other emotions. This approach yields more cross-cultural similarities in colour-emotion associations (see Chapter 2; D'Andrade & Egan, 1974; Ou et al., 2018). They can also be analysed in terms of the *extent* to which each emotion is associated, as compared to other nations/conditions/populations of interest. This approach yields more cross-cultural differences in colour-emotion associations (see Chapters 2 and 4; Hupka et al., 1997; Madden et al., 2000).

Universality in the Domain of Colour

Colour Semantics. The first universal in the domain of colour could be the existence of words to describe colour. Colour words seem to exist in almost every human language and the number of basic colour terms vary between 2 and 11 or 12 (Androulaki et al., 2006; Berlin & Kay, 1969; Davidoff et al., 1999; Kay & Maffi, 1999; Paramei, 2005; Rosch, 1973; Uusküla et al., 2012). Furthermore, it has been suggested that these basic colour terms have appeared in languages in a fixed evolutionary sequence, which is also universal. Berlin and Kay (1969) reported that in a language with just two colour terms, there was always a distinction between WHITE and BLACK (LIGHT/WARM and DARK/COOL; Kay & Maffi, 1999; Rosch, 1973). In a language with three colour terms, there was also a term for RED+ (i.e., RED and other WARM hues), and so on (see Table S 42). In a later revision, Kay and Maffi (1999) specified four main principles for the emergence of colour terms: 1) to name several significant entities like colour, family, animals, plants; 2) to distinguish between black and white; 3) to distinguish between warm (red and yellow) and cool (green and blue) primaries; and 4) to distinguish red (see Figure S 8). Hence, while there is a large variability in the number of the basic colour terms present in a language, the sequence in which these colour terms evolutionary appear in languages is largely universal.

Table S 42. The evolutionary sequence of colour category acquisition, presented by Berlin and Kay (1969).

Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI	Stage VII
White *and* Black	+ Red	+ Green *or* + Yellow	+ Yellow *or* + Green	+ Blue	+ Brown	+ Purple *and/or* + Pink *and/or* +Orange *and/or* +Grey

Note. Colour categories are named after their focal points. The evolutionary sequence has been revised several times. See Figure S 8 for the most recent version.

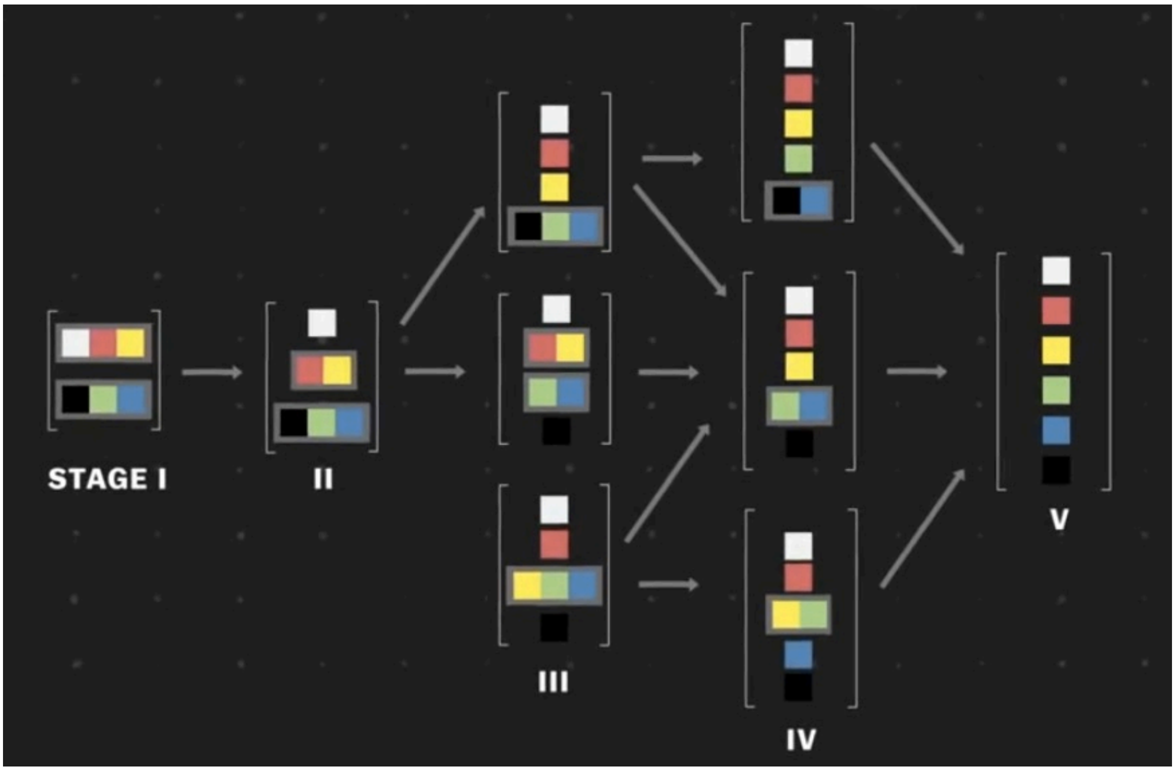

Figure S 8. The evolutionary sequence of colour category acquisition and its three possible trajectories.

The sequence supposes that the colour space becomes more finely partitioned as more colour terms are acquired. In Stage I, the partitioning of the colour space starts by separating the colour space into light and warm hues vs. dark and cool colours. In Stage II, warm colours are separated from the light colours. In Stage III, warm colours might be further portioned into yellow and red, or dark colours might be separated from cool colours, the latter to form a GRUE (green+blue) category. The third possibility suggests that yellow, green, and blue might form a single category while light and red colours are separated. The ontogeny of such system is less known and the system is rare. In Stage IV, separation happens further with either separating green from cool and dark colours, or yellow from warm colours, or blue from yellow, green, and blue colours. At the final Stage V, the basic partitioning has happened. All the remaining basic colour categories – orange, pink, grey, brown, and purple, – might emerge at any point of the evolutionary sequence. (Kay & Maffi, 1999). The image was taken from *Vox* (https://www.youtube.com/watch?v=gMqZR3pqMjg).

Colour terms are found in industrialised languages. When it comes to non-industrialised languages, the picture is more obscure. For instance, some languages lack an umbrella term for “colour” (Brindle, 2016; Conklin, 1986; Wierzbicka, 2008). Some of these languages might nevertheless possess words describing colour-like properties (Brindle, 2016; Conklin, 1986) while others might not (Surrallés, 2016) but see (Kay, 2018). Wierzbicka (2008) argued that some languages indeed have no word for “colour” or colour-like properties. She argued that the sole reason why researchers find such “colour” words is because they impose their industrialised understanding of the world on these very different languages and cultures. She argued that a human universal is a concept of “seeing” rather than a concept of “colour”. That is, every language has words to describe properties of the visual world, whether or not these properties refer to colour.

Apart from the existence of colour terms and their universal evolutionary sequence, many other aspects of colour language are not universal. Languages, even the closely related ones, differ in the lexemes that refer to the specific colour categories (e.g., *vert* vs. *green* vs. *žalia* to mean GREEN in French, English, and Lithuanian). Thus, translation of colour terms is not a trivial matter (Stanley-Thorne, 2002; Uusküla, 2020). Languages also differ in other features like how codable colour terms are (Majid et al., 2018), the conceptual meaning of colour terms (Jackson et al., 2019b), or colour metaphors (G. He, 2011; Kalda & Uusküla, 2019; Rodriguez Redondo & Molina Plaza, 2007).

Colour Perception. When it comes to linking colour terms with colour perception, researchers have looked at different aspects of perceived colours, including focal colours, which are the best examples of each colour category. In their seminal work, Berlin and Kay (1969) proposed that focal colours should be universal. Later, Regier and colleagues (Regier et al., 2005) affirmed this claim by testing focal colours in 110 unwritten languages from non-industrialised societies within the scope of the *World Color Survey*. While the focal colours in these languages clustered close together, the researchers only tested focal colours for six colour categories. Other studies reported some variations in the exact loci of focal colours when more colour categories were assessed (Uusküla & Bimler, 2016b). Furthermore, there seems to be even more variation regarding the boundaries of colour categories. Participant responses vary within (Sturges & Whitfield, 1995) as well as between (Davidoff et al., 1999; Majid et al., 2015; Roberson et al.,

2005) languages where they draw boundaries between neighbouring colour terms. American English speakers, for instance, mostly disagree about the boundaries between *blue* and *green*; *purple* and *pink*; and *red* and *pink* (Sturges & Whitfield, 1995).

Recently, Parraga and Akbarinia (2016) employed an empirical computational approach to studying boundaries of colour categories. They asked participants to choose a colour that perceptually appears exactly between two neighbouring colour terms (e.g., *blue* and *green*). Using such an approach, the researchers derived distributions of perceptual colours constituting boundaries of different colour categories. Their research again demonstrated that there is no single boundary between two neighbouring colour terms but rather the boundaries of different participants roughly follow a normal distribution. Yet, these boundaries could be predicted by a relatively simple physiologically plausible model, by taking into account weights of cone-opponent contrasts. Taken together, both universal and relative aspects exist in colour categorisation. These aspects are used as arguments in the long-stranding debate between universalists and linguistic relativists, the latter also known as proponents of the Sapir-Whorf hypothesis (e.g., Davidoff, 2001; Regier & Kay, 2009; Witzel, 2019).

Colour Preferences. Colour preferences have some universal characteristics. In almost all studies, performed in Western and non-Western countries, researchers have reported that blue or green-blue were favoured by the majority (among many, Eysenck, 1941; Fortmann-Roe, 2011; Granger, 1955; Jiang et al., 2020; Jonauskaite et al., 2016; Jonauskaite, Dael, et al., 2019; Palmer & Schloss, 2010; Taylor, Schloss, et al., 2013; Taylor & Franklin, 2012; Yu et al., 2021; Y. Zhang et al., 2019). Similarly, these studies have also found that darker shades of yellow and orange (i.e., brown) were the least favourite colours. As mentioned above, aversion to yellow, green, and brown have been identified as one of the four universal factors in affective responses to colour (D. R. Simmons & Asher, 2010).

However, these findings have not been replicated in a small-scale society of Himba speakers in Namibia (Taylor, Clifford, et al., 2013). The latter did not like blue hues more than yellow hues. Instead, Himba colour preferences were driven by chroma, as they liked saturated hues, especially red, orange, yellow, chartreuse, and green. In fact, saturated but cold hues (cyan, blue, and purple) received somewhat lower preference ratings than the other hues, going to the opposite direction than the expected "universal" preference for blue. Light or dark versions of the same hues were not liked and did not vary by hue (i.e., preference line was nearly flat). The authors explained these results as a novelty effect, since Himba people lack saturated colours in their natural environments. Moreover, their colour preference was not explained through associations with objects, despite a hope that this mechanism is universal (Palmer & Schloss, 2010). Unexpectedly, Himba males liked colours that were associated with negative objects and disliked colours that were associated with positive objects. Taken together, Himba people do not display any of the supposedly universal aspects of colour preferences.

Furthermore, universal biologically-guided **gender differences** in colour preferences have been suggested (Hurlbert & Ling, 2007). The latter authors demonstrated that females like reddish-pinkish hues more than males across two cultures – the UK and China. They explained this difference through differently weighed cone contrasts, which supposedly feed into an evolutionary mechanism of sex-specific functional specialisation of hunter-gatherers. Put plainly, pre-historic women supposedly collected berries while men went hunting, which is why women have developed a higher preference for reddish-pinkish colours (for a more nuanced view on gender roles in hunter-gatherers, see (Dyble et al., 2015; Gurven & Hill, 2009; Haas et al., 2020).

Gender differences in colour preferences have been reported in a number of earlier and subsequent studies in different countries, supporting the hypothesis (Al-Rasheed, 2015; Bonnardel et al., 2018; Cohen, 2013; W. He et al., 2011; Hurlbert & Ling, 2007; Jonauskaite, Dael, et al., 2019; Park, 2013; Pranckevičienė et al., 2009; Sorokowski et al., 2014b; Witzel, 2015, but see, Eysenck, 1941; Ou et al., 2004; Taylor & Franklin, 2012). That said, gender differences in colour preferences vary by age. Preference for reddish-pinkish colours seems more pronounced in girls than adult women (Jonauskaite, Dael, et al., 2019), suggesting that colour preferences change during development. Moreover, gender differences in colour preferences are not apparent in infants (Franklin et al., 2010; Jadva et al., 2010), going against the supposition that such differences are in-born. Gender differences emerge only at the age of two when children begin construing their gender identity (Cunningham & Macrae, 2011; LoBue & DeLoache, 2011; Wong & Hines, 2015, but see, Zentner, 2001). Thus, it is possible that social norms rather than biological mechanisms are guiding gender differences in colour preferences.

The support for the social hypothesis comes from at least three observations. First, the gender difference in preference for pink and blue seems to stem from males avoiding pink more so than females preferring pink over blue (e.g., Davis et al., 2021; Jonauskaite, Dael, et al., 2019; LoBue & DeLoache, 2011). The evolutionary mechanism, however, is predicting that females should prefer pink due to its biological connotations (i.e., ripe berries). This mechanism is not predicting that males should avoid pink. The latter can be explained through social connotations of pink (i.e., femininity, childishness). Second, gender differences in colour preferences correlate with one's gender identity so that children who had a reverse gender identity also preferred colours of the other gender (Chiu et al., 2006). Third, gender differences have not been observed in most non-industrialised societies, including in Namibia, Peruvian Amazon, Vanuatu, Congo, and Tanzania, where local people have little access to the world-wide popular media and mass-produced objects (Davis et al., 2021; Groyecka et al., 2019; Taylor, Clifford, et al., 2013) but see a research study in Papua New Guinea (Sorokowski et al., 2014a). If gender differences in colour preferences were indeed guided by biological mechanisms, they should be invariant across cultures.

Taken together, there are universal aspects of colour preferences, at least when measured in industrialised societies. When testing less industrialised societies, the same colour preferences and their gender differences could not be replicated. These findings question how universal colour preferences actually are and why studies across industrialised societies nevertheless observe such a high consistency in responses.

Colour-Related Behaviour. Few studies have assessed universality of colour-related behaviour. One important reason is the lack of evidence for many colour effects on cognition and emotion (e.g., see *Discussion: Behaviour*, and Gnambs et al., 2020; Steele, 2014; von Castell et al., 2018). Nevertheless, one psychological effect of colour has been claimed to be universal. A series of studies have demonstrated that red increases female attractiveness (Elliot & Niesta, 2008; Elliot & Pazda, 2012; Guéguen, 2012; Guéguen & Jacob, 2012, 2014; Meier et al., 2012). More specifically, men consistently indicate that women, who are dressed in red or whose pictures are presented on a red background, are more attractive and that they would be more willing to date these women when compared to women dressed in other colours. Men also give more tips to waitresses dressed in red or wearing a red lipstick (Guéguen & Jacob, 2012, 2014). These studies, however, have been performed in the Western context where red is repeatedly paired with sex and romance in culture and arts (i.e., Scarlet Letter, red-light district, Valentine's day, etc.).

Recently, the same red effect on attractiveness was replicated in a remote culture in Burkina Faso where such cultural meanings are less common (Elliot et al., 2013). The researchers took these findings as an indication that red-attractiveness link is universal and represents a fundamental, physiologically grounded association. Such physiologically grounded associations could be slightly flushed and lighter face of women during ovulation (Bullivant et al., 2004) and a flushed face when sexually aroused (Lynn et al., 2007). Recognising such signals improves ones evolutionary fitness and therefore is encouraged (Dixson, 1983). Even more recently, the red effect on attractiveness was confirmed in a meta-analysis, combining 41 studies and 98 samples (Lehmann et al., 2018). Although significant, the effect of red on attractiveness was small, explaining why some studies failed to find the expected effect (Francis, 2013; Hesslinger et al., 2015; Roberts et al., 2010).

Universality in The Domain of Emotion

Emotion Semantics. Emotion as a phenomenon can be identified in virtually all languages even though some language lack words for the umbrella term "emotion" or for specific emotions (Ogarkova, 2013). Moreover, there is a common underlying structure of emotion concepts. As described in the introduction (*What is Emotion? Emotion as a point on an affective dimension*), across languages, emotions can be robustly represented by three affective dimensions, namely valence, arousal, and power (Osgood et al., 1975; Shaver et al., 1987, 1992). Recently, such an underlying structure was further tested with the new psycholinguistic tool – the GRID instrument (Fontaine et al., 2013b; Fontaine & Scherer, 2013; Soriano et al., 2013). The GRID instrument was designed to better understand the lay meaning of emotion terms and uncover the underlying affective dimensions. Participants saw 24 culturally relevant and representative emotion terms and were asked to rate these terms on 142 emotion features. Each feature was related to one of the five emotion components (i.e., appraisal, bodily reaction, expression, action tendency, and feeling; (Scherer, 2005). The 34 samples of participants came from 27 countries and spoke 23 languages (Soriano et al., 2013). The principal component analysis across all samples revealed a four-factor solution. Valence was the most important factor, followed by power, arousal, and novelty in this order (also see, Fontaine et al., 2007; Gillioz et al., 2016). The massive overlap of the semantic profiles of the emotion terms across 23 languages vouched for a universal underlying connotative structure of emotion terms.

However, when it comes to the actual words that speakers use to describe emotions, variability is larger. Lomas (2016) compiled a non-exhaustive list of 216 “untranslatable” emotion terms, that is, of words without exact equivalents in English. The list includes words like *hygge* (Danish; a deep sense of place, warmth, friendship, and contentment), *saudade* (Portuguese; melancholic longing, nostalgia, dreaming wistfulness), and *hrepenenje* (Slovenian; nostalgia for something that hasn’t happened yet). The list of untranslatable words is constantly growing (see https://www.drtimlomas.com/) and highlights cross-linguistic diversity of emotion words. Furthermore, a recent study questioned if emotion terms that can be translated (e.g., *love*, *joy*) have the same conceptual meaning across languages (Jackson et al., 2019b). Jackson and colleagues addressed this question by looking at colexification in 2,474 languages. Colexification is phenomenon in which semantically related concepts are named with the same word (e.g., *joy* (English) and *joie* (French)). Their analyses revealed significant variations in emotion concept colexifications, further predicted by geographic and linguistic proximity. In other words, semantic meaning of emotions was diverse across languages, but speakers of related languages conceptualized emotions more similarly. Nonetheless, like in the GRID study, emotion colexification networks revealed universal underlying structure characterized by valence and arousal. Taken together, individual emotion words and their conceptual meanings show cross-cultural diversity while the underlying affective structure of these words is likely to be universal.

Emotion Perception. According to the basic emotion theory, basic emotions are displayed and recognised universally, irrespective of one’s linguistic and cultural background (Ekman, 1992b; Ekman et al., 1969, 1987; Ekman & Cordaro, 2011; Ekman & Friesen, 1971). Although supported by earlier studies (Ekman et al., 1969; Ekman & Friesen, 1971; Scherer et al., 2001), recent accounts raised doubts whether emotion display and recognition are indeed universal (Cordaro et al., 2018; Crivelli, Jarillo, et al., 2016; Gendron et al., 2014b, 2014a, 2018; Jack et al., 2009, 2016; Nelson & Russell, 2013). They provided more nuanced accounts and highlighted both universal and culture-specific features of emotion recognition.

Crivelli, Jarillo and colleagues (2016) asked Spaniards and Trobrianders (Papua New Guinea) to choose a happy, sad, angry, disgusted, or fearful face from an array of smiling, pouting, scowling, gasping, and nose scrunching Caucasian faces. Spaniards achieved an accuracy of 83-100%, with disgust being the worst and happiness the best recognised expressions. Trobrianders also recognised the happy faces the best (58%) and rarely confused them with other emotions. The recognition of the remaining facial expressions was lower: sadness – 46%, fear – 31%, disgust – 25%, and anger – 7%. These emotions were also confused with each other. For instance, sad faces were equally often recognised as fearful, and fearful faces as disgusted or angry. These results suggest the existence of cultural variability in the interpretation of the affective content of facial expressions. In fact, gasping facial expression often displays anger and threat rather than fear in another small-scale Melanesian society (Crivelli, Russell, et al., 2016). Therefore, recognising a gasping face as angry rather than fearful goes in line with the specific cultural experience.

With higher exposure to a foreign culture, comes improved recognition of facial emotions. A meta-analysis of emotion recognition within and across cultures concluded that emotions were recognised above chance in all conditions (Elfenbein & Ambady, 2002). Therefore, there is a degree of universality in emotion recognition. However, emotion recognition was higher when members of the same national, ethnic, or regional group displayed emotions, suggesting an in-group advantage in emotion recognition. Emotion recognition also became faster with higher exposure to a foreign culture (Elfenbein & Ambady, 2003). Taken together, emotion display and recognition may have some innate universal features that are further shaped by specific cultural experience, which may enhance or hamper emotion recognition of foreign faces.

Additional Material for the Colour Connotation Theory

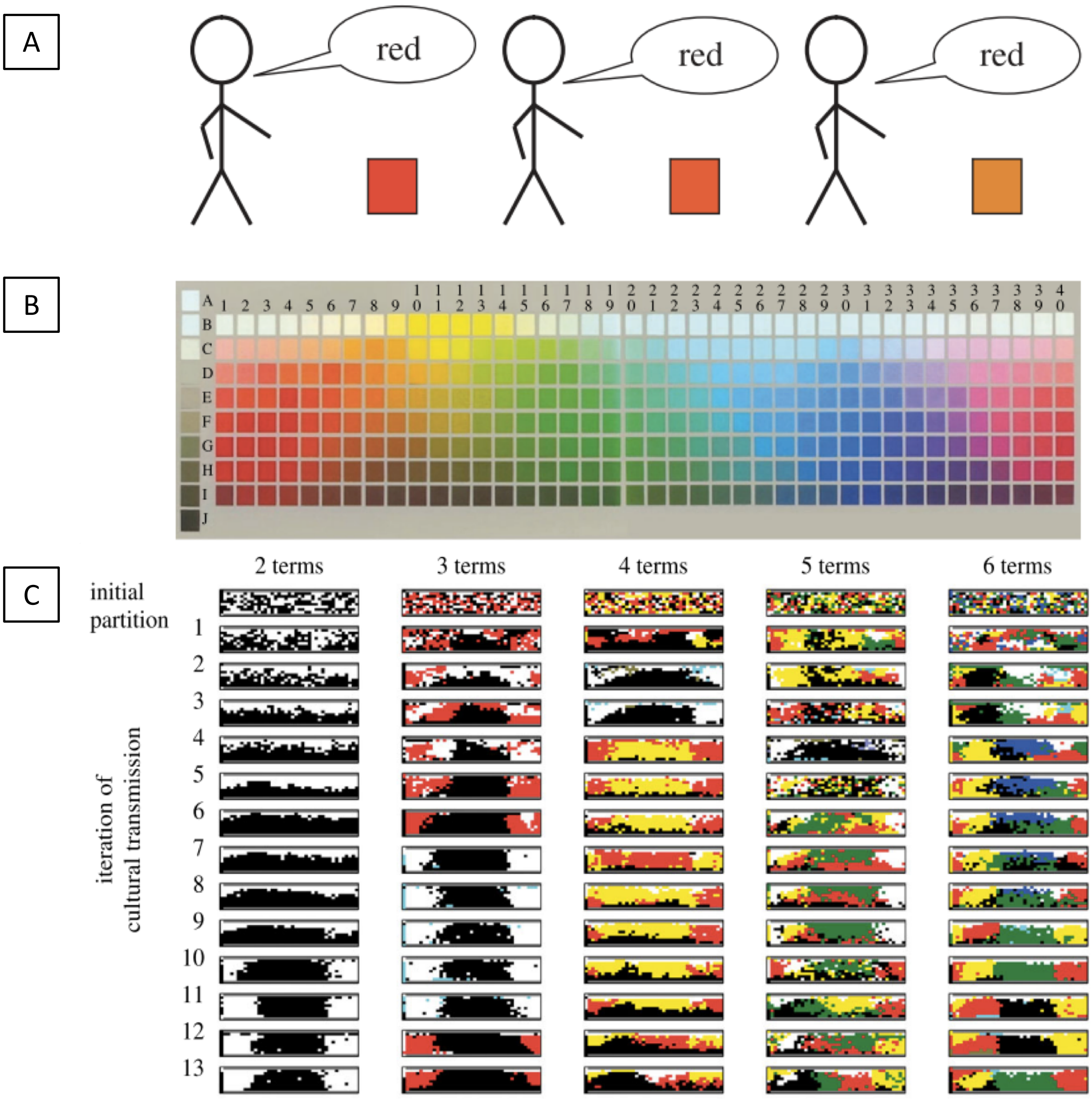

Figure S 9. Simulation of cultural transmission of colour terms through iterative learning from Xu et al., 2013.

(A) Visual example of iterative learning, how one speaker teaches another speaker a colour name. (B) The array of Munsell colour chips. (C) Examples of colour term systems produced in the experiment by 13 generations of speakers. Transmission proceeds down the column and each column exemplifies a colour system with a different number of colour terms (between two and six). The colours mark colour chips that were labelled with the same colour term and do not correspond to the colours denoted by the terms. See Xu et al. (2013) for further explanations, from whom the figure was adapted.

Cross-Modal Correspondences with Colour

Colour-shape correspondences. A Bauhaus movement artist Wassily Kandinsky (1912, 1947) famously proposed systematic correspondences between red-square, yellow-triangle, and blue-circle, claiming that these correspondences are inherent see (“Kandinsky” in Figure S 10.). Subsequent studies also found systematic colour-shape correspondences but they did not always correspond to the ones proposed by Kandinsky (Albertazzi et al., 2013; N. Chen et al., 2015; N. Chen & Watanabe, 2020; Dreksler & Spence, 2019; Hanada, 2019; Makin & Wuerger, 2013). In one study, Kandinsky’s correspondences were the least preferred among German participants (Jacobsen, 2002). Instead, German participants associated red with triangles, yellow with circles, and blue with squares. Jacobsen (2002) claimed these colour-shape correspondences reflect real-world correspondences: yellow-circle-sun, red-triangle-warning sign (see “Association” in Figure S 10.). Italian participants had different correspondences, and associated red with circles, yellow with triangles, and blue with squares (Albertazzi et al., 2013). The same correspondences were replicated in Japanese participants too (N. Chen et al., 2015) and were also proposed by other Bauhaus movement artists, who disagreed with Kandinsky (Dreksler & Spence, 2019); see “Dissident” in Figure S 10.). Nonetheless, Albertazzi and colleagues (Albertazzi et al., 2015) argued that Kandinsky was “right” after observing a tendency to associate acute angles with warm colours and obtuse angles with cool colours. In brief, while systematic colour-shape correspondences exist within studies, they seem to be less generalisable across studies, and especially across cultural contexts.

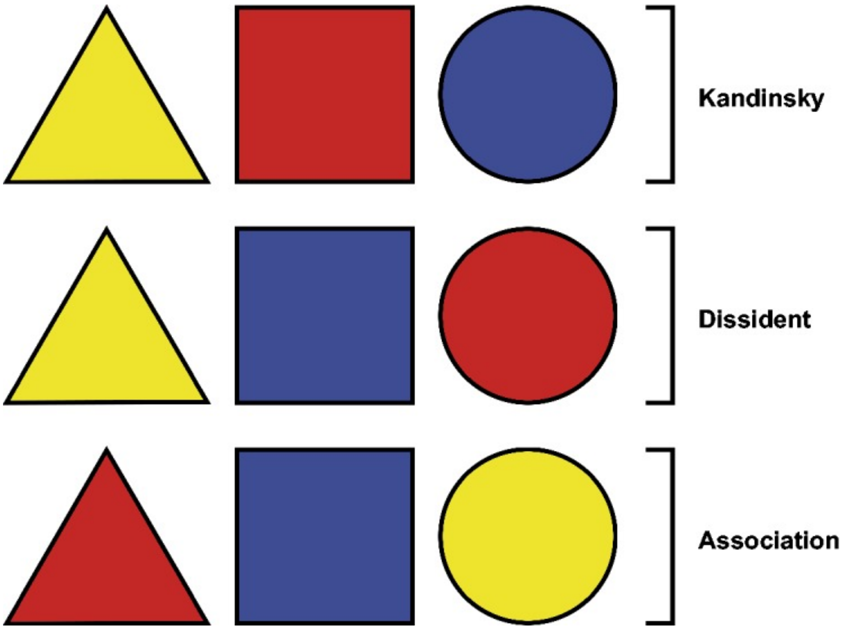

Figure S 10. Colour-shape correspondences.

"Kandinsky" correspondences proposed by W. Kandinsky (1912, 1947). "Dissident" correspondences proposed by Bauhaus movement artists, who disagreed with Kandinsky. Similar correspondences observed in Japan (N. Chen et al., 2015) and Italy (Albertazzi et al., 2013). "Association" correspondences observed in the German sample and supposedly represent naturally-occurring correspondences (e.g., sun – yellow circle; (Jacobsen, 2002). Figure taken from (Dreksler & Spence, 2019).

Colour-sound correspondences. Research has shown that louder and higher pitch sounds are associated with lighter or brighter colours (Anikin & Johansson, 2019; Marks, 1987). After controlling for lightness, louder and higher pitch sounds were associated with more chromatic colours and yellower, as opposed to bluer, hues (Hamilton-Fletcher et al., 2017). The brightness-pitch correspondence was also detected in the blind – the blind associated higher pitch tones with the terms *white*, *red*, *orange*, and *yellow*, and lower pitch tones with the terms *blue*, *brown*, *purple*, and *black* (Saysani, 2019). The latter finding indicates that colour-sound correspondences have a conceptual component, at least when it comes to colours. Such colour-sound correspondences seem to be encoded in natural languages too. Johansson and colleagues (2019) analysed 245 languages and concluded that more sonorous (i.e., "louder") vowels, such as "a" or "o", were over-represented for colour terms of bright colours and more sonorous consonants, such as “w”, “y”, or “r”, were over-represented for colour terms for saturated colours. The English words *yellow* and *red* are good examples of such tendencies.

Colours are not only associated with pure tones, simple sounds, or phonemes, but also with more complex auditory stimuli like **music** (Bhattacharya & Lindsen, 2016; Hu, 2020; Isbilen & Krumhansl, 2016; Lindborg & Friberg, 2015; Palmer, Langlois, et al., 2015; Palmer, Schloss, Xu, et al., 2013; Whiteford et al., 2018). Research has shown that participants choose lighter, more saturated, and yellower colours for faster music in major tone and darker, less saturated, and bluer colours for slower music in minor tone (Palmer, Schloss, Xu, et al., 2013). Beyond tone, and when looking across musical genres, loud, punchy, and distorted music is associated with darker, redder, and more saturated colours (Whiteford et al., 2018). Overall, such colour-music correspondences seem to be mediated by emotion associations (see the *emotion mediation hypothesis* in Palmer, Schloss, Xu, et al., 2013; C. Spence, 2020a). That is, music that sounds “happy” is associated with “happy” colours, music that sounds “agitated” is associated with “agitated” colours, etc. The emotion mediation hypothesis contrasts *the direct link hypothesis*, claiming that colour-music correspondences arise from direct correspondences of auditory and perceptual features of music and colour, respectively (Caivano, 1994).

Colour-odour correspondences. Many systematic colour-odour correspondences are food-related (see reviews in C. Spence, 2020b; Zellner, 2013). As such, the smell of *caramel* or *cinnamon* is associated with brown, the smell of *strawberry* with pink and red, the smell of *lemon* with yellow, the smell of *peppermint* with green or blue, and so on (Demattè et al., 2006; Jacquot et al., 2016; Spector & Maurer, 2012). Colour-odour correspondences are more consistent when one can identify and accurately name an odour (Goubet et al., 2018; Kaeppler, 2018), highlighting the importance of semantic knowledge. For instance, participants who named a *citrus* smell as “lemon” matched this smell to shades of yellow, while those who named the same smell as “lime” chose shades of green (Kaeppler, 2018). Thus, colour-odour correspondences are mediated through object associations (C. Spence, 2020b).

Semantic-mediation for colour-odour correspondences has been demonstrated in a study with Maniq speakers. Maniq people are a hunter-gatherer tribe in South East Asia, who have a more diverse vocabulary of abstract odour terms than many other languages (Majid et al., 2018; Majid & Burenhult, 2014). While, for instance, Dutch speakers often refer to odours in relation to objects (e.g., this *smells like banana*), Maniq speakers have non-object-related words for odours (e.g., *lspəs* refers to fragrant smells like *banana* but also *dried durian*, *coconut milk*, *cigarettes,* and *garlic*). Thus, Maniq speakers should display more diverse colour correspondences with the same odours than Dutch speakers. The latter finding was demonstrated at least for some odours, especially, for the odours of *banana*, *peanut butter*, and *mustard* (de Valk et al., 2017). While Dutch speakers had relatively consistent colour-odour correspondences, driven by the object colours (e.g., yellow for *banana* smell), Maniq speakers associated completely different and varied colours, as is seen in Figure S 11.

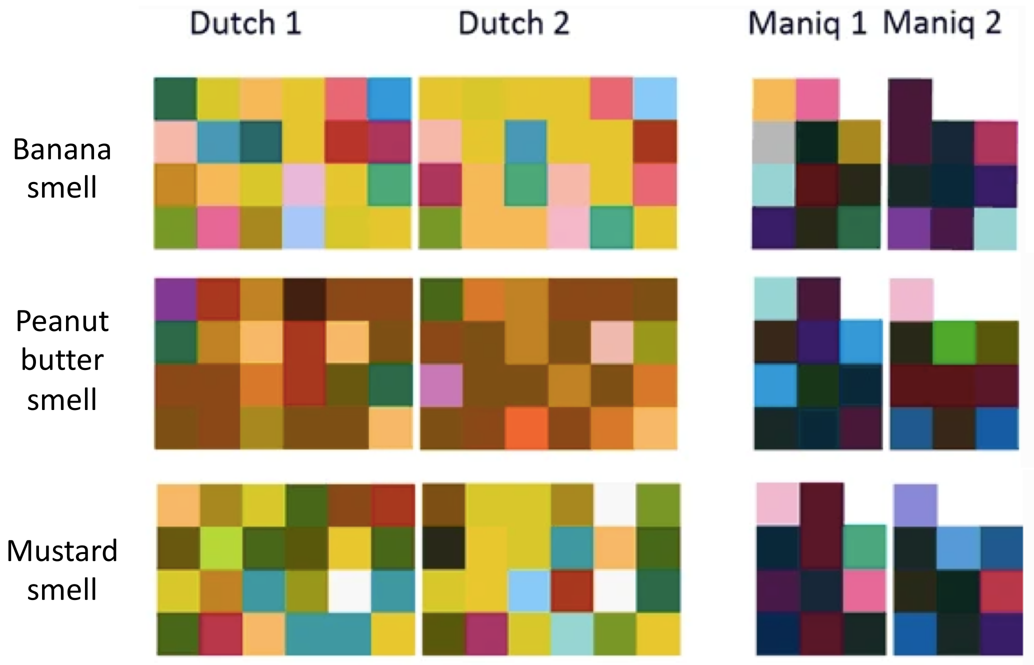

Figure S 11. Colour-odour correspondences in Dutch and Maniq speakers, adapted from de Valk et al. (2017).

The figure has been adapted to exemplify colour correspondences with three odours: *banana*, *peanut butter* and *mustard*. Colour selections are displayed across two testing times (Dutch 1 / Maniq 1 = first testing, Dutch 2 / Maniq 2 = second testing).

Beyond food-related context, colour-odour correspondences have been studied for **fragrancies** and perfumes (Kim, 2013; Schifferstein & Howell, 2015; Schifferstein & Tanudjaja, 2004; Yang & Chen, 2015; Zellner et al., 2008). Kim (2013) reported that perfumes of the *floral* family were frequently matched to bright red and warm colours, while perfumes of the *woody* family were matched to cool and dark colours (shades of green and blue). Perfumes of the *fresh* family were also matched to cool but bright and vivid colours. Colours assigned to a unisex perfume packaging depended on whether participants thought the perfume was meant for men or women (Zellner et al., 2008). As in other domains and consistent with colour-gender stereotypes (e.g., (Cunningham & Macrae, 2011; Del Giudice, 2012), participants chose a blue packaging as suitable for a perfume identified as masculine. They never chose pink for “masculine” perfumes. When the same perfume was identified as feminine, thought, participants chose pink packaging more often than other colours. Thus, non-food-related colour-odour correspondences seem more likely to be mediated via affect or social norms than food-related colour-odour correspondences, which are rather mediated via direct object correspondences.

Colour-taste/flavour correspondences. First, there are colour correspondences with **basic tastes**, such as adding red to a solution increases its perceived sweetness (J. Johnson & Clydesdale, 1982; C. Spence, 2019b) and participants rate red solutions as the sweetest and most pleasant just from visual inspection (Hoppu et al., 2018). When given taste words, participants consistently associate *sweet* with red, pink or purple, *sour* with yellow or green, *salty* with white, and *bitter* with black (C. Spence et al., 2015; Woods & Spence, 2016). However, there are no consistent colour correspondences with a more recently discovered *umami* taste (C. Spence, 2019b).

When it comes to **flavours**, beverage colours can shift the perception of flavour towards the expected ones (DuBose et al., 1980; Zampini et al., 2007). In DuBose et al.’s (1980) study, a cherry flavoured beverage coloured in red was nearly always identified as indeed having a cherry flavour, while the same beverage coloured in green was identified as having a lime flavour. Participants reported tasting flavours even in flavourless but coloured beverages, congruent with expectations. Red beverages tasted like cherry, strawberry, or raspberry; orange beverages tasted like orange (fruit); and green beverages tasted like lime or lemon.

Beyond experimentally manipulated beverages, colours impact perceived flavours of wine (Oberfeld et al., 2009; Q. J. Wang & Spence, 2019), coffee (Carvalho & Spence, 2019), and popcorn (Harrar et al., 2011), among other foods (for reviews, see C. Spence, 2018, 2019a, 2019b). Overall, it seems that colour-flavour correspondences are semantically mediated (Shankar et al., 2010), although likely to a smaller extent than colour-odour correspondences. Both types of correspondences are learnt culturally through associations between coloured objects and their respective odours and flavours.

Symbolic Colour Meanings

Evarts (1919) described diverse symbolic meanings of colours through history and across cultural traditions. Accordingly, in many cultures, *white* is a symbol of God, light, purity, innocence, chastity, and modesty. *White* can also be a symbol of sickness and of death due to the absence of hue. *Black* is the opposite of *white*, and so it is a symbol of personified evil and death. Being a symbol of death, *black* can also become a symbol of rebirth or a regeneration of a soul. As *black* is associated with night, it also carries a symbolic meaning of beauty and repose. *Red* is a symbol for heat, passion, destruction, and love due to its association with fire. *Red* is truly an ambivalent colour. On the one hand, *red* is a symbol for hate, anger, blood, cruelty, and sin. On the other hand, *red* is a symbol for fertility, femininity, passion, and love. Evarts believed that darker shades of *red* relate closer to hate while lighter shades of *red*, namely pink or rose, relate to love.

Blue is again a symbol for divinity and heavens, due to its associations with sky. According to Evarts, darker shades of *blue* resemble *black* and so they carry similar symbolism of death and sadness. Dark shades of *blue* can also symbolise sin, serenity, coldness, contemplation and melancholy. *Blue* also symbolises aristocracy and social virtues of truth, honour, fidelity, constancy, serenity, and wisdom. When it comes to *green*, it is a symbol of freshness, youth, growth, regeneration, activity, charity, and hope. On the negative side, *green* symbolises defeat and flight, despair, degradation, and folly.

The symbolism of *yellow* is determined by sun, which gives light and warmth, and mature harvests. Thus, *yellow* is a symbol of creative force, luminosity, cheerfulness, sublimation, human goodness, and constancy. With its association with harvest, *yellow* is also a symbol of nutritional levels of mankind. On the negative side, *yellow* symbolises degradation, sickness, and sin, especially of adultery or theft. *Orange* also symbolises adultery or rather indissoluble marriage. *Brown*, as a colour of dead vegetation, symbolises decay and death, degradation, distrust, deceit, and sadness. *Brown* can also symbolise strength, vigour, and solidity. *Purple* symbolises truth and love as well as controlled passion, being at the same time hot and cold. Furthermore, *purple* is a symbol of sovereignty, to indicate the divine right of kings. *Purple* also symbolises wrong, evil, falseness, and it is a colour of mourning, especially among royalty. Finally, *pink* carries the meanings of *red*, *white*, and *purple*. Lighter shades of *pink* symbolise love while darker shades of *pink* are symbols of royalty.

These symbolic meanings of colour have been determined through the analysis of historical sources, including artworks and written depictions. Nonetheless, if colours indeed carry significant symbolic meanings, these symbols should be evident also when assessing colour meanings empirically. Kaya and Epps (2004) asked participants to report their emotional responses in relation to the presented colour patches. Participants reported not only emotion words but also affectively laden words. For instance, *green* was associated with trees and nature, peace and hope. *Yellow* was associated with summer, blooming flowers, and sun. *Red* was again ambivalent as it bore associations with Satan and evil, love and romance, fight and blood. Finally, *black* was associated with death, mourning, tragic events, night and darkness as well as richness, power, and wealth.

Sutton and Altarriba (2016a) employed a reverse paradigm and asked participants to name a colour term for each emotion and emotion-laden word. The majority of the negative emotion-laden words were associated with *black* or *red*. *Black* was the most common choice for words like *burial, cemetery, death*, *corpse*, *funeral*, *disaster*, *divorce*, *cancer*, *nightmare*, *lie*, and *poison*. *Red* was the most common choice for *bloody*, *danger, criminal, demon, hell, injury, suicide, pain,* and *war. Red* was also the most common choice for some positive emotion-laden words, including *kiss*, *holiday*, *romantic*, and *victory*. Many colour associations with emotion-laden words could be grounded in perceptual experiences. For instance, *diamond* was associated with *white*; *cash*, *lucky*, *money*, and *outdoor* with *green*; *heaven* and *god* with *white*; and *trophy* and *treasure* with *gold*. Both of these studies demonstrate diversity in the symbolic meaning of colour, with divergent and convergent meanings of the same colour.

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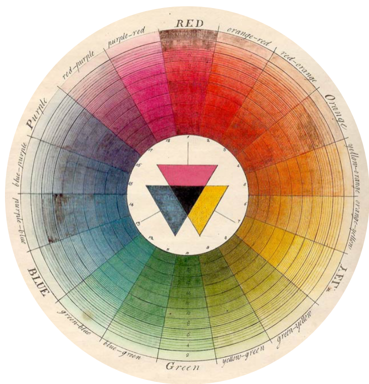

Universality of colour-emotion associations

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