Colour-emotion associations in individuals with red-green colour blindness

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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.

Colour-Emotion Associations In Individuals With Red-Green Colour Blindness

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1 **Abstract**

2 Colours and emotions are associated in languages and traditions. Some of us may convey

3 sadness by saying *feeling blue* or by wearing black clothes at funerals. The first example is a

4 conceptual experience of colour and the second example is an immediate perceptual experience

5 of colour. To investigate whether one or the other type of experience more strongly drives

6 colour-emotion associations, we tested 64 congenitally red-green colour-blind men and 66 non-

7 colour-blind men. All participants associated 12 colours, presented as terms or patches, with 20

8 emotion concepts, and rated intensities of the associated emotions. We found that colour-blind

9 and non-colour-blind men associated similar emotions with colours, irrespective of whether

10 colours were conveyed via terms ($r = .82$) or patches ($r = .80$). The colour-emotion associations

11 and the emotion intensities were not modulated by participants' severity of colour blindness.

12 Hinting at some additional, although minor, role of actual colour perception, the consistencies in

13 associations for colour terms and patches were higher in non-colour-blind than colour-blind men.

14 Together, these results suggest that colour-emotion associations in adults do not require

15 immediate perceptual colour experiences, as conceptual experiences are sufficient.

16 **Word count:** 8,167 words (main text only).

1. Introduction

18   We *feel blue*, *see red*, and have some *black days*. As Westerners, we might wear *white* to

19   weddings and *black* to funerals. These examples show that colours and affective meanings are

20   associated in natural languages and cultural traditions. Moreover, colour-emotion associations

21   are highly similar across cultures (Adams & Osgood, 1973; D'Andrade & Egan, 1974; Gao et

22   al., 2007; Ou et al., 2018; Jonauskaite et al., 2020a). This similarity is indicative of a human

23   psychological universal, which is a mental attribute shared by all or nearly all healthy human

24   beings (see Norenzayan & Heine, 2005). This universal might be determined by conceptual

25   knowledge, because emotion associations were similar when matched to colour patches or colour

26   words, indicating that immediate colour perception is not necessary for these associations to be

27   reported (Jonauskaite et al., 2020b). To test this possibility, we recruited individuals with

28   congenital red-green colour blindness. Such individuals have never seen colours in the same way

29   as individuals with intact colour vision due to their congenital deficiencies (Linhares, Pinto &

30   Nascimento, 2008). Yet, colour-blind individuals have been exposed to similar conceptual

31   information, namely similar cultural and linguistic environments as non-colour-blind individuals

32   (Byrne & Hilbert, 2010). If colour-emotion associations in the two groups are similar,

33   irrespective of whether seeing colour patches or colour terms, we have good reasons concluding

34   that conceptual colour-emotion associations are so well established that sufficient, and that

35   immediate colour perception is not essential for such associations to be reported.

36   We are aware of several older and more recent studies investigating the extent to which colour-

37   emotion associations are shared across cultures (Adams & Osgood, 1973; D'Andrade & Egan,

38   1974; Hupka et al., 1997; Madden, Hewett & Roth, 2000; Gao et al., 2007; Ou et al., 2018;

39   Jonauskaite et al., 2020a). Some studies reported cross-cultural similarities in, and even claimed

40   universality for, associations between brighter colours and positivity (Specker et al., 2018),

41   associations between colours and affective dimensions (Adams & Osgood, 1973; Gao et al.,

42   2007; Ou et al., 2018), or colours and emotion terms (D'Andrade & Egan, 1974). Examples of

43   these associations include *red* being an active, warm and strong colour, *blue*, *green*, and *white*

44   being positive colours, dark colours being heavy while desaturated colours being passive. Other

45   studies highlighted cross-cultural differences. For instance, *envy* was associated with *black*, *red*,

46   *green*, *yellow*, or *purple* depending on the nation (Hupka et al., 1997). These studies, however,

47   used different methods, usually testing a limited number of colours, emotions, and/or cultures.

48   Recently, Jonauskaite and colleagues (Jonauskaite et al., 2020a) tested 240 colour-emotion

49   associations in 30 nations resulting from associations between 12 colour terms and 20 emotion

50   concepts. For each colour term, participants were free to associate as many emotions as they felt

51   appropriate, in their native language. Results revealed high similarity in the way colours and

52   emotions were associated across nations (average correlation was $r = .88$). These cross-cultural

53   results indicate that humans largely share how they associate colours with emotions, at least

54   when colours are presented as terms. Presentation mode does not seem to matter, though, as

55   similar emotions have been associated with colour patches, at least when participants were tested

56   in a Western context. More precicely, in another study, Swiss adults again associated the 12

57   colours with the 20 emotion concepts (Jonauskaite et al., 2020b). One group of participants

58   associated emotions with basic colour terms and the other group with focal colours that best

59   represent these basic colour terms. Both groups chose similar emotions for the same colour

60   concepts, irrespective of whether they were presented as terms or patches (correlation between

61   groups was $r = .82$). In a different study, Wang and colleagues (2014) reported high similarity in

62   term-patch associations for *blue* but not *red*. In their study, Chinese participants evaluated r*ed*

63   more positively as a term than a patch. Overall, with some potential exceptions, these results

64   suggest that seeing a colour is not key to decide on colour-emotion associations, at least once

65   individuals have reached adulthood.

66   High similarities in colour-emotion associations across cultures and presentation mode do not

67   reveal the mechanisms that drive the formation of shared colour-emotion associations.

68   Considering potential mechanisms, one mechanism might be shared perceptual experiences by

69   most humans (see also, Palmer & Schloss, 2010; Jonauskaite et al., 2019a). In this case, a direct

70   perceptual experience of colour might lead to an affective experience. For instance, looking at a

71   colour would make one *feel* a certain emotion or immediately remind of a particular emotion.

72   Another mechanism might be shared conceptual knowledge, accessed and transmitted through

73   language (see Xu et al., 2013, for cultural transmission of colour terms). In that case, colours and

74   emotions would be conceptually associated without necessarily meaning that immediate colour

75   perception itself evokes associations with affective experiences.

76   To test the relative importance of conceptual versus immediate colour experience, we suggest for

77   this study to test colour-emotion associations in populations with colour vision deficiencies. The

78   most frequent colour vision deficiency is congenital red-green colour blindness. Here, affected

79   individuals can discern a smaller number of colours than individuals with complete colour vision

80   (Neitz & Neitz, 2000; Linhares, Pinto & Nascimento, 2008). Red-green colour blindness, also

81   called Daltonism after John Dalton (Dalton, 1798), affects around 8% of the male population and

82   around 0.6% of the female population of European-Caucasian origin (Sharpe et al., 1999; Birch,

83   2012). Such individuals confuse certain colours along the red-green axis (e.g., *red* and *brown*,

84   *green* and *brown*, *pink* and *grey*, *grey* and *green,* etc.; Moreira et al., 2014) and likely see the

85   world in bluish-yellowish colours (Judd, 1949; Byrne & Hilbert, 2010). Individuals with red-

86   green colour blindness have never seen certain colours the way individuals with intact colour

87   vision do, but have been exposed to their shared cultural and linguistic environments (e.g., traffic

88   colours; Almustanyir & Hovis, 2020). Accordingly, if individuals with and without red-green

89   colour blindness display similar colour-emotion associations, we can argue that shared

90   conceptual knowledge is sufficient for colour-emotion associations to occur.

91   Studies assessing colour naming and colour arrangements support the importance of conceptual

92   knowledge. In case of colour naming, colour-blind individuals were able to name colours

93   indicating that they learned to differentiate colours, irrespective of whether they look the same or

94   different to colours perceived by individuals with intact colour vision (Jameson & Hurvich,

95   1978; Paramei, 1996; Bonnardel, 2006; Nagy et al., 2014; Moreira et al., 2014). Bonnardel

96   (2006) found that consensus in colour naming ranged between 52% and 74% for colour-blind

97   and non-colour-blind individuals. The highest consensus emerged when participants had to name

98   colour chips using one of eight colour terms (i.e., constrained colour naming task; 74%

99   consensus). Some of the chips were focal colours (i.e., the best examples of each colour

100 category) while others were not. The lowest consensus emerged for a task that least involved

101 language (i.e., freely grouping colour chips into colour categories, 52% consensus). For colour

102 arrangements, colour-blind individuals mentally arranged colours more similarly to non-colour-

103 blind individuals when colours were presented as terms than as patches (Shepard & Cooper,

104 1992; Saysani, Corballis & Corballis, 2018a). When presented with terms, colour-blind

105 individuals used three colour axes (i.e., red-green, blue-yellow, and dark-light) to arrange

106 colours. When presented with patches of focal colours, colour-blind individuals collapsed

107 colours along the red-green axis and used only two axes to arrange colours. Taken together,

108 conceptual knowledge seems essential for colour naming and colour arrangements. Nonetheless,

109 colour terms and colour patches might be treated somewhat differently by colour-blind

110 individuals. If so, colour-blind individuals might also treat colour-emotion associations

111 differently when actually reading a colour term or seeing a colour patch.

112 To test the importance of conceptual knowledge and immediate perceptual colour experience, we

113 assessed 240 colour-emotion associations in individuals with and without red-green colour

114 blindness using a previously established methodology (Jonauskaite et al., 2019c, 2020b,a). Part

115 of each group associated emotion terms with colour terms while the remainder associated

116 emotion terms with colour patches displaying focal colours. Emotion terms were presented in a

117 circular format (Scherer, 2005; Scherer et al., 2013). We compared colour-emotion associations

118 between colour-blind and non-colour-blind individuals as well as between colour terms and

119 colour patches in each group. If shared conceptual knowledge is sufficient for colour-emotion

120 associations to occur, we would expect high similarities in colour-emotion associations between

121 individuals with and without colour blindness. We would also expect high similarity in colour-

122 emotion associations between colour terms and colour patches in colour-blind individuals. If,

123 however, previous or immediate perceptual colour experiences are necessary for consistent

124 colour-emotion associations to occur, we would expect differences in colour-emotion

125 associations between individuals with and without colour blindness (e.g., see Álvaro et al., 2015,

126 for colour preferences). These differences should be more pronounced when actual perceptual

127 colours (i.e., colour patches) rather than colour terms are evaluated, since perceptual colours

128 appear differently to individuals with and without colour blindness (Byrne & Hilbert, 2010). We

129 would also expect lower consistency between colour terms and colour patches in colour-blind

130 individuals.

131 In addition to comparing colour-blind and non-colour-blind individuals, we further modelled

132 colour blindness as a continuum. We tested whether the strength of colour blindness predicted

133 colour-emotion associations. We chose to treat colour blindness as a continuum due to variations

134 in physiological and behavioural expressions of colour blindness. Red-green colour blindness

135 results from changes in the photopigments in the cone receptors coding for long ("reddish"; L-

136 cones) or medium ("greenish"; M-cones) wavelengths (Parry, 2015). For some individuals, cones

137 are completely missing (dichromatic vision), while for others, they are malfunctioning

138 (anomalous trichromatic vision). The degree of perceptual confusion is related to the degree of

139 individuals' physiological impairments (Neitz & Neitz, 2000). Many previous studies considered

140 only individuals with dichromatic vision (Jameson & Hurvich, 1978; Shepard & Cooper, 1992;

141 Paramei, Bimler & Cavonius, 1998; Moreira et al., 2014; Saysani, Corballis & Corballis, 2018a).

142 However, such individuals comprise just 28.5% of all colour-blind men of European origin (i.e.,

143 2.3% of the general population of European males; Sharpe et al., 1999). Thus, we decided to

144 freely sample from the colour-blind population and include both individuals with dichromatic

145 vision and anomalous trichromatic vision (similar to, Paramei, 1996; Bonnardel, 2006; Nagy et

146 al., 2014).

2. Materials & Methods

2.1 Participants

149 We recruited 130 men, 64 were colour-blind by self-report, which was confirmed with colour

150 vision tests (see *Colour Vision Tests* for further details). About half of the participants took part

151 in the colour terms condition (associating terms with emotions, Table 1) and the other half took

152 part in the colour patches condition (associating patches with emotions, Table 1). All participants

153 lived in Switzerland. Most participants were either students or staff members of a local

154 university. They were fluent French speakers, apart from one participant who was excluded from

155 the analyses (see Table 1). Age did not differ between study groups, $F(3, 125) = 1.50$, $p = .218$.

156

157   [Insert Table 1 around here]

158

159 Based on a related previous publication, where we ran a 2 x 12 mixed-design MANOVA to

160 compare emotion associations between terms and patches (Jonauskaite et al., 2020b), we

161 expected a large effect size ($V = .55$). We entered this effect size in the G*Power sample size

162 calculator (Faul et al., 2007) together with the expected alpha (.05) and beta (.80) levels. We

163 obtained 26 participants as a minimal total sample size. Yet, we decided to collect more

164 participants to be able to also consider a variability in the expression of colour blindness as well

165 as exclude weak colour-blind participants from part of the analyses.

166   Participation was voluntary and remunerated with monetary reward (CHF 20 in gift vouchers).

167   The study was conducted in accordance with the principles expressed in the Declaration of

168   Helsinki (World Medical Association, 2013). We received ethics approval from the Research

169   Ethics Commission of the University of Lausanne (C_SSP_032020_00003).

170   **2.2.   Colour Stimuli**

171   We used *red, orange, yellow, green, turquoise, blue, purple, pink, brown, white, grey,* and *black*

172   as colour stimuli. Eleven of these colour stimuli represent the principal colour categories

173   (Biggam, 2012). We also included *turquoise* because it covers the blue-green range. In the terms

174   condition, colour stimuli were presented as French colour terms written in black ink (Spence,

175   1989, see Table S 1). In the patches condition, colour stimuli were presented as colour patches.

176   Colour patches displayed the best exemplars of each colour category (i.e., focal colours, Table 2,

177   Lindsey & Brown, 2014), and have been used in native French speakers in Switzerland

178   (Jonauskaite et al., 2020b).

179

180   [Insert Table 2 around here]

181

182   **2.3.   Emotion Assessment**

183   We used the Geneva Emotion Wheel (GEW 3.0; Figure 1; Scherer, 2005; Scherer et al., 2013) to

184   measure emotion associations with colours. GEW is a validated self-report measure of the

185   feeling component of emotion. Twenty emotion concepts are represented along the

186   circumference of a wheel. These emotion concepts are organized along two axes. The horizontal

187   axis represents *valence,* also known as evaluation or pleasantness (positive vs. negative). The

188   vertical axis represents *power*, also known as control, dominance, or potency (strong vs. weak).

189   Emotion concepts can further be categorised in terms of *arousal,* also known as activation (high

190   arousal vs. low arousal), based on complementary research studies (Fontaine, 2013; Soriano et

191   al., 2013). We reported this categorisation in a previous related study (Jonauskaite et al., 2020b)

192   and here in Table S 2. Circles of increasing size connect the centre of the wheel with the

193   circumference of the wheel. These circles denote five degrees of emotion intensity, coded from 1

194   (smallest circle; weakest intensity) to 5 (biggest circle; strongest intensity), or 0 if no emotion is

195   chosen (little square). The Swiss Centre for Affective Sciences provides the validated French

196   version of the GEW (Table S 1.).

197

198   [Insert Figure 1 around here]

199

200   **2.4.   Colour Vision Tests**

201   Red-green colour blindness varies in severity. This variation can be behaviourally captured with

202   the three colour vision tests – the Ishihara test (Ishihara, 2000), the Farnsworth test (Farnsworth,

203   1947), and the Lanthony test (Lanthony, 1978a,b). The detailed testing and scoring of the tests

204   appear in Supplementary material.

205   **2.5.**   **Procedure**

206   We performed the colour terms and colour patches conditions as similarly as possible, but had to

207   also account for the different study material. The procedure was identical to a previous study

208   (Jonauskaite et al., 2020b). Below, we detail what was comparable for conditions (see *Common*

209   *to Both Conditions*), followed by the description of the terms condition procedure and the

210   patches condition procedure.

211   **2.5.1. *Common to Both Conditions***

212   Upon arrival to the welcome room, we gave participants relevant study information. Those who

213   agreed to participate signed the written informed consent form (see Figure 2 for procedure).

214   Next, we tested participants' colour vision with the Ishihara test. All colour vision tests were

215   conducted as physical tests under the same conditions of artificial office light. Afterwards,

216   participants were invited to the testing room. The computer monitor was the only source of

217   illumination in the testing room. All participants performed the experiment on the same monitor:

218   Eizo ColourEdge CG247 24.1" (inches) LCD display, with an in-built self-calibration sensor. We

219   set the temperature of the monitors to 6500 K, gamma: 2.2, contrast: 100%, and brightness:

220   120cd/m². Resolution was 1920 x 1200 pixels and the frame rate was 59.90 Hz. The eye-screen

221   distance was approximately 70 cm.

222   Participants completed either the terms or the patches condition. Experimenters were available

223   for questions at any point during the experiments. After the main experiment, participants

224   returned to the welcome room and completed the Farnsworth D-15 and Lanthony D-15 tests.

225   These tests were given in a randomised order across participants. Once participants completed

226   the first test, the completed test was hidden and they were asked to complete the second test.

227   Upon the completion of both tests, participants were debriefed and remunerated. Participants

228   were invited to ask questions and received a debriefing sheet with written information and

229   contact details for future references. The entire experiment took between 50 and 70 minutes.

230   *2.5.2. Colour Terms Condition*

231   The colour terms condition was performed in the laboratory testing room. We used an existing

232   online survey link (https://www2.unil.ch/onlinepsylab/colour/main.php); also used to collect data

233   remotely for a larger ongoing International Colour-Emotion Survey online (Mohr et al., 2018;

234   Jonauskaite et al., 2020a). In the current experiment, participants accessed the online survey on

235   our laboratory computer to ensure comparability between the two experimental conditions.

236   The survey started with an information page. On the next pages, the task was explained, namely

237   to associate colour terms with emotion concepts, presented on the GEW (see *Emotion*

238   *Assessment*). Participants had to perform a manipulation check exercise to make sure they

239   understood the task. In particular, participants had to correct the responses of an imaginary

240   person (Peter). In the following experimental part, participants saw the 12 colour terms written in

241   black ink on a grey background, presented sequentially and in random order above the GEW (see

242   *Colour stimuli* and Table 2). Participants were asked to choose one, several, or none of the GEW

243   emotion concepts that they associated with each colour term. They also rated intensities of each

244   associated emotion by choosing circles of different sizes, which were later coded as 1-5 ratings.

245   After the colour-emotion association task, participants provided demographic information and

246   saw results from a previous related marketing experiment in graphic format.

2.5.3. *Colour Patches Condition*

248   We performed the colour patches condition in the same laboratory testing room as the terms

249   condition. The experiment started with an information page explaining the task, namely to

250   associate colour patches with emotion concepts, presented on the GEW (see *Emotion*

251   *Assessment*). Participants proceeded to the next page if they understood the task. Then, three

252   example colours followed. For the examples as well as for the main task, participants were

253   presented with a colour patch (15° x 15° subtended angle) on a neutral grey background (see

254   Table 2). They were instructed to focus on the colour patch. Participants chose when to move to

255   the subsequent page but no earlier than 5 seconds after it appeared on the screen. On each

256   subsequent page, in analogy to the terms condition, participants associated one, several, or none

257   of the GEW concepts with the target colour patch and rated the intensity of each associated

258   emotion concept. While associating emotions, participants could see the target colour on the

259   small GEW squares as well as on the chosen intensity circles (Figure 2.B Experiment 2). There

260   were 12 experimental colour patches presented in randomised order (see *Colour stimuli* and

261   Table 2). Colour values were adapted for the monitor (see *Apparatus* in Supplementary

262   material). We collected these data in the laboratory to ensure accurate colour presentation.

263   After the colour-emotion association task, participants completed the colour-naming task with

264   the same colour patches. Each colour patch was presented 12 times in randomised order and

265   paired with one of the colour terms (total of 144 presentations). Participants had to evaluate how

266   likely they would be using this *colour term* to name a particular *colour patch* from "not at all"

267   (converted to 0) to "very likely" (converted to 100). For example, participants would see a *green*

268   colour patch and have to respond how likely they would be to call it *purple.* Not all participants

269   in the patches condition performed the colour-naming task (22 colour-blind and 33 non-colour-

270   blind completed the task). We decided to add this task after the first 10 colour-blind participants

271   had been tested. After these two tasks, participants provided demographic information,

272   analogous to the terms condition, on a paper questionnaire.

273

274   [Insert Figure 2 around here]

275

276   **2.6. Data Preparation**

277   The raw data can be accessed following this link: https://forsbase.unil.ch/project/study-public-

278   overview/16969/0/. We cleaned the data based on colour blindness scores by creating the Colour

279   Blindness Index.

280   ***2.6.1.   Colour Blindness Index***

281   We used errors on the colour blindness tests to create a single measure of colour blindness – the

282   *Colour Blindness Index*. This index served a dual purpose. First, we could ensure accurate

283   participant re-categorisation into colour-blind and non-colour-blind participants. Second, we

284   obtained a continuous measure of colour blindness.

285   To determine the colour blindness indices, we used a principal component analysis on the

286   correlation matrix of the number of errors on the Ishihara test, the number of crossing errors on

287   both the Farnsworth D-15 and Lanthony D-15 tests, and the number of neighbour errors on both

288   the Farnsworth D-15 and Lanthony D-15 tests (see Supplementary material for scoring). The

289   principal component analysis resulted in two factors with Eigenvalues greater than 1 (i.e., 2.79

290   and 1.07 respectively for factors 1 and 2). The first factor explained 55.7% of the variance and

291   the second factor explained an additional 21.3% of the variance. The first factor separated the

292   colour-blind participants from the non-colour-blind participants, and we called this factor the

293   colour blindness index (see Figure S 1A). The second factor was difficult to interpret and did not

294   separate participants by colour blindness (see Figure S 1B). Thus, we disregarded it. In Table S

295   3, we present the loadings of each item for both factors.

296   The visual inspection of the frequency distribution of the colour blindness index (Figure S 1A)

297   indicates that it might consist of three different distributions. The most leftward distribution (< -

298   0.6) included only non-colour-blind participants plus one colour-blind participant by self-report.

299   Thus, the latter participant was most likely not colour-blind; he passed both the Farnsworth D-15

300   and Lanthony D-15 tests, and was categorised as "unsure" on the Ishihara test. The most

301   rightward distribution (> 0.2) included only colour-blind participants by self-report, thus, these

302   participants had relatively strong colour blindness. The intermediate distribution (between -0.6

303   and 0.2) included both self-reported colour-blind and non-colour-blind participants. Participants

304   with these scores might have (very) weak colour blindness or no colour vision impairment but

305   nevertheless made errors for other reasons (e.g., inattentiveness).

306   For the group-level analyses (see below), we considered only the two extreme groups (i.e., re-

307   categorised non-colour-blind and re-categorised colour-blind participants). Such a categorisation

308   ensured that participants grouped in the non-colour-blind group were indeed not colour-blind

309   (had low colour blindness index scores) while participants grouped in the colour-blind group

310   were indeed relatively strongly colour-blind (i.e., had high colour blindness index scores) [1].

311   There were 25 colour-blind and 25 non-colour-blind participants in the terms condition. There

312   were 24 colour-blind and 31 non-colour-blind participants in the patches condition (see Table S

313   4).

314   **2.7.   Data Analyses**

315   We ran the subsequent analyses using these new and improved colour blindness categories. We

316   set alpha levels for all tests at .050. All analyses were two-tailed. Across statistical tests, where

317   appropriate, we controlled for familywise errors (Type I error) using False Discovery Rate

318   (FDR) correction and marked the corrected p-values as p_{FDR} (Benjamini & Hochberg, 1995). We

319   performed analyses and created graphs with the R v.3.4.0 and SPSS v.25.

320   *2.7.1.   Group-Level Analyses*

321   For these analyses, we compared the re-categorised non-colour-blind and colour-blind

322   participants, as described in the section *Colour Blindness Index*. We continue labelling them

323   colour-blind and non-colour-blind participants, for simplicity.

324   **2.8.1.1. Specific Colour-Emotion Associations.** We started the analyses by investigating the

325   specific emotion concepts associated with colours. We calculated the proportion of participants

326   who associated a specific emotion concept with a specific colour by dividing the number of

327   participants who chose each emotion concept for each colour by the total number of participants

---

[1] 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/

328 in that group (e.g., colour-blind, terms condition). The proportion of participants was calculated

329 separately for colour-blind participants and non-colour-blind participants for each condition

330 (terms or patches) separately. The proportion values were the dependent variable, which varied

331 from 0 (very unlikely association, no one chose it) to 1 (very likely association, everyone chose

332 it).

333 To compare the *pattern* of emotion associations, we created four 12 x 20 (colours x emotions)

334 representation matrices using the proportion values to compare colour blindness groups and

335 colour presentation modes. $Matrix_{CB-term}$ contained colour-emotion associations of colour-blind

336 participants associating colour terms with emotion concepts, while $Matrix_{Non-CB-term}$ contained

337 analogous associations of non-colour-blind participants (terms condition). $Matrix_{CB-patch}$

338 contained colour-emotion associations of colour-blind participants associating colour patches

339 with emotion concepts while $Matrix_{Non-CB-patch}$ contained analogous associations of non-colour-

340 blind participants (patches condition; see Figure 3).

341 Then, we used Pearson matrix correlations to compare $Matrix_{CB-term}$ vs. $Matrix_{Non-CB-term}$ and

342 $Matrix_{CB-patch}$ vs. $Matrix_{Non-CB-patch.}$ These matrix correlations formed the basis for the Pattern

343 Similarity Index (PSI), which reflects the degree of similarity in the pattern of colour-emotion

344 associations between two matrices. A PSI score of 1 indicates perfect pattern similarity, and a

345 PSI score of 0 indicates complete pattern dissimilarity. Furthermore, to compare the similarity of

346 emotion associations for each colour, we calculated PSI_{colour}. PSI_{colour} was estimated per colour

347 using Pearson correlations between colour-blind participants and non-colour-blind participants,

348 and between colour terms and colour patches.

349   To identify which colour-emotion associations differed between colour-blind and non-colour-

350   blind participants, we further used Fisher's exact tests (Fisher, 1922). The test compared the

351   proportion of participants endorsing a particular colour-emotion association (yes/no; n = 240)

352   between colour-blind and non-colour-blind participants for terms and for patches separately. All

353   comparisons were FDR corrected (Benjamini & Hochberg, 1995).

354   **2.8.1.2. Emotion Intensity.** The dependent variable *emotion intensity* was calculated by

355   averaging intensity ratings assigned to emotion concepts associated with each colour and for any

356   colour (i.e., "overall"). Emotion intensity varied from 1 (weak) to 5 (strong), unless no emotion

357   concept was chosen (coded as missing value).

358   A 2 x 2 independent-samples ANOVA compared average *emotion intensity* of all colours

359   together (i.e., "overall") between re-categorised study groups (colour-blind vs. non-colour-blind)

360   and conditions (colour terms vs. colour patches). Afterwards, series of independent-samples *t*-

361   tests compared *emotion intensity* ratings per colour between colour-blind and non-colour-blind

362   participants for terms and for patches separately, and between terms and patches for colour-blind

363   and non-colour-blind participants separately. All comparisons were FDR corrected (Benjamini &

364   Hochberg, 1995).

365   **2.8.1.3. Supplemental Analyses.** Additionally, we analysed colour associations with emotion

366   dimensions and colour naming. As these were supplementary analyses, the method and results

367   are presented in the Supplementary material.

368   ***2.8.2. Individual-Level Analyses***

369   We tested whether the *presence* of colour-emotion associations depended on the degree of colour

370   blindness (i.e., colour blindness index). To this end, we fitted a logistic model with repeated

371   measures using *glmer* function in lme4 package (Bates et al., 2015). We used the likelihood ratio

372   test to test for significance of individual predictors and their interactions. The predictor variables

373   were the colour blindness index, colour presentation mode (2 levels, independent), colour (12

374   levels, repeated), and emotion (20 levels, repeated). We also tested for the three interactions

375   between the colour blindness index and i) colour presentation mode, ii) colour, and iii) emotion.

376   The outcome variable was presence of colour-emotion association (yes/no). These analyses were

377   performed on all participants (n = 129).

378   **3. Results**

379   **3.2.   Colour Blindness Scoring**

380   The 2 x 2 MANOVA on the number of errors in colour blindness test scores indicated that

381   colour-blind participants made significantly more errors than non-colour-blind participants on all

382   tests. However, their performance did not differ by condition (terms or patches). More details are

383   presented in the Supplementary material and Table S 5.

384   **3.3.   Group-Level Analyses**

385   *3.3.1. Specific Colour-Emotion Associations*

386   Some colour-emotion associations were prominent in both study groups. For instance, *red-love*,

387   *red-anger*, *yellow-joy*, *pink-love* and *brown-disgust* were chosen by 50% or more of colour-blind

388   as well as non-colour-blind participants (terms and patches combined). The majority of colour-

389   blind participants also associated *orange* with *joy*, *yellow* with *pleasure*, and *blue* with *pleasure*.

390   The majority of non-colour-blind participants also associated *red* with *pleasure*, *red* with *hate*,

391   *yellow* with *amusement*, *turquoise* with *joy* and *pleasure*, *blue* with *interest*, *pink* with *joy* and

392   *pleasure*, *grey* with *sadness* and *disappointment,* and *black* with *fear*. See Figure 3 for visual

393   representation of all colour-emotion associations (and supplemental tables for the numeric

394   values: Table S 10, Table S 11, Table S 12, and Table S 13).

395   **3.2.1.1. Colour-Blind vs. Non-Colour-Blind Participants.** After having described the specific

396   colour-emotion associations, we compared the pattern of colour-emotion associations between

397   study groups and conditions. The matrix correlations, PSI, were overall high. PSI comparing

398   emotion associations with colour terms (Matrix$_{\text{CB-term}}$ vs. Matrix$_{\text{Non-CB-term}}$) showed high

399   similarity, $r = .82$, $R^2 = .672$, $p < .001$, and so did PSI comparing emotion associations with

400   patches (Matrix$_{\text{CB-patch}}$ vs. Matrix$_{\text{Non-CB-patch}}$), $r = .80$, $R^2 = .637$, $p < .001$ (see Figure 3). These

401   correlation coefficients were of similar strength, $z = -0.63$, $p = .529$. These results imply that

402   colour-blind participants and non-colour-blind participants associated similar emotions,

403   irrespective of whether a colour was presented as a term or a patch.

404   Furthermore, colour-specific PSI$_{\text{colour}}$ comparing emotion associations between colour-blind and

405   non-colour-blind participants for each colour were high for colour terms, $r = .60-.97$, $R^2 = .355-$

406    $.939$, $p_{FDR} < .006$, and for colour patches, $r = .55-.92$, $R^2 = .548-.924$, $p_{FDR} < .012$, see Table 3.

407   The only exception was *purple*, for colour terms, $r = .07$, $R^2 = .004$, $p_{FDR} = .781$, and for colour

408   patches, $r = .09$, $R^2 = .007$, $p_{FDR} = .721$. These results indicate that the similarity between colour-

409   blind and non-colour-blind participants held across all colours, whether a term or a patch was

410   presented, with *purple* being an exception.

411 Fisher's exact tests were used to identify any differences between the specific colour-emotion

412 associations between the two study groups, separately for each condition. No specific colour-

413 emotion comparisons were significant suggesting that no colour-emotion specific association

414 differed between the two study groups ($p_{FDR} \geq .39$). Thus, despite low correlations for *purple*,

415 we could not detect specific emotion associations driving this dissimilarity.

416 **3.2.1.2. Colour Terms vs. Colour Patches.** Furthermore, we compared the pattern of emotion

417 associations with colour terms and colour patches, respectively, for each study group separately.

418 The matrix-to-matrix correlations, PSI, were again overall high. PSI comparing emotion

419 associations between colour terms and colour patches in colour-blind participants (Matrix$_{CB\text{-term}}$

420 vs. Matrix$_{CB\text{-patch}}$) showed high similarity, $r = .74$, $R^2 = .552$, $p < .001$, and so did PSI comparing

421 emotion associations between colour terms and colour patches in non-colour-blind participants

422 (Matrix$_{Non\text{-}CB\text{-term}}$ vs. Matrix$_{Non\text{-}CB\text{-patch}}$), $r = .83$, $R^2 = .683$, $p < .001$ (see Figure 3). However, the

423 correlation coefficient in colour-blind participants was significantly lower than in non-colour-

424 blind participants, $z = -2.59$, $p = .010$. These results mean that similar emotions were associated

425 with colour terms and with colour patches by non-colour-blind participants as well as by colour-

426 blind participants, but the latter did so to a lower extent.

427 Furthermore, colour-specific PSI$_{colour}$ comparing emotion associations between colour terms and

428 colour patches for each colour were high for colour-blind participants, $r = .46\text{-}.89$, $R^2 = .214\text{-}$

429 $.795$, $p_{FDR} < .040$, and for non-colour-blind participants, $r = .49\text{-}.96$, $R^2 = .243\text{-}.929$, $p_{FDR} < .027$,

430 see Table 3. The exception again was *purple*, associations of which did not correlate for colour-

431 blind participants, $r = .26$, $R^2 = .066$, $p_{FDR} = .273$. Correlations for *green* in colour-blind

432 participants were significant but low ($p = .040$). These results indicated that the similarity

433   between colour terms and colour patches was equally true for colour-blind and non-colour-blind

434   participants, with the exception of *purple*.

435   Fisher's exact tests were used to identify differences for specific colour-emotion associations

436   between conditions, separately for colour-blind and non-colour-blind participants. No specific

437   colour-emotion comparisons were significant ($p_{FDR} \geq .57$). Thus, despite a low correlation in

438   colour-blind participants between *purple* as a patch and as a term, we could not detect specific

439   emotion associations driving this dissimilarity.

440

441   [Insert Figure 3 around here]

442   [Insert Table 3 around here]

443

444   *3.3.2. Emotion Intensity*

445   The 2 x 2 ANOVA revealed a significant main effect of condition, $F(1, 101) = 14.8, p < .001, \eta_p^2$

446   $= .123$, indicating that more intense emotions were associated with colour terms than colour

447   patches by both study groups. There was no significant main effect of study group, $F(1, 101) =$

448   $2.44, p = .121, \eta_p^2 = .024$, indicating that colour blind and non-colour-blind participants

449   associated equally intense emotions overall. Finally, the interaction between study group and

450   condition was not significant, $F(1, 101) = 0.23, p = .440, \eta_p^2 = .006$. For differences by colour,

451   see supplemental material (Table S 6, Table S 7, Table S 8, and Table S 9).

452   **3.4.   Individual-Level Analyses**

453   The multilevel logistic regression model was overall significant, $LR(63) = 876$, $p < .001$, $_{pseudo}R^2$

454    $= .028$ (Cox & Snell), .047 (Nagelkerke). Both, colour, $LR(12) = 161$, $p < .001$, $_{pseudo}R^2 = .005$

455   (Cox & Snell), .009 (Nagelkerke), and emotion, $LR(20) = 675$, $p < .001$, $_{pseudo}R^2 = .022$ (Cox &

456   Snell), .037 (Nagelkerke), were significant predictors of whether colours and emotions were

457   associated or not. In contrast, the colour blindness index was not a significant predictor of the

458   probability of colour-emotion associations, $LR(1) = 0.03$, $p = .865$, $_{pseudo}R^2 < .001$ (Cox & Snell),

459    $< .001$ (Nagelkerke). Hence, the probability of colour-emotion associations did not vary by

460   degree of colour blindness. Condition was not a significant predictor either, $LR(1) = 0.14$, $p =$

461    $.711$, $_{pseudo}R^2 < .001$ (Cox & Snell), $< .001$ (Nagelkerke).

462   The two-way interaction between the colour blindness index and colour was significant, $LR(11)$

463    $= 23.4$, $p = .016$, $_{pseudo}R^2 = .001$ (Cox & Snell), .001 (Nagelkerke). Higher colour blindness index

464   resulted in lower probability of emotion associations with *red*, $\beta = -0.17$, $z = -2.08$, $p = .037$.

465   However, this effect was weak and disappeared after FDR correction ($p_{FDR} = .44$). The colour

466   blindness index was not a significant predictor for other colours, $ps_{FDR} = .96$. The other two-way

467   interactions between the colour blindness index and emotion, $LR(19) = 9.58$, $p = .96$, $_{pseudo}R^2 <$

468    $.001$ (Cox & Snell), $< .001$ (Nagelkerke), and the colour blindness index and condition, $LR(1) =$

469   1.73, $p = .189$, $_{pseudo}R^2 < .001$ (Cox & Snell), $< .001$ (Nagelkerke), were not significant.

470   Given these zero results, we wished to estimate the likelihood that, indeed, the colour blindness

471   index is unlikely to predict the probability of colour-emotion associations. We examined the key

472   predictor of interest (colour blindness index) by estimating the Bayes factor using Bayesian

473   Information Criteria (Wagenmakers, 2007; Jarosz & Wiley, 2014). The Bayes factor compared

474   the fit of the data under the null hypothesis with the fit of the data under the alternative

475   hypothesis. The estimated Bayes factor (null/alternative; BF_{01}) was 245:1, suggesting that the

476   data were 245 times more likely to occur under the null hypothesis than the alternative

477   hypothesis. Reversely, the data were 0.004 times more likely to occur under the alternative than

478   the null hypothesis (BF_{10}).

479   **4. Discussion**

480   Colours are associated with emotions (Wexner, 1954; Adams & Osgood, 1973; Valdez &

481   Mehrabian, 1994; Kaya & Epps, 2004; Fugate & Franco, 2019; Tham et al., 2019; Schloss,

482   Witzel & Lai, 2020) and these associations might be universal across cultures (Adams &

483   Osgood, 1973; D'Andrade & Egan, 1974; Gao et al., 2007; Ou et al., 2018; Jonauskaite et al.,

484   2020a). If the assumption on universality holds true, we have to ask whether these associations

485   originate from our shared i) conceptual, abstract understanding of the world (Xu, Dowman &

486   Griffiths, 2013), or ii) perceptual experience of inhabiting the globe (Palmer & Schloss, 2010).

487   Recently, Jonauskaite, et al. (2020b) showed that colour-emotion associations were similar for

488   colour patches and colour terms in young Swiss adults. These results indicate that i) conceptual

489   colour experiences seem sufficient for colour-emotion associations to occur, and ii) immediate

490   perceptual colour experiences do not seem necessary.

491   To further assess these suggestions, we tested men with congenital red-green colour blindness as

492   well as men with intact colour vision. We tested men, because they have a much higher

493   incidence of colour blindness than women (Sharpe et al., 1999; Birch, 2012). Our participants

494   associated 12 colours with 20 emotion terms, and rated the emotion intensities (see also

495   Jonauskaite et al., 2020b). Half of our participants associated colour terms, and the other half

496   associated colour patches. Participants who associated colour patches also named them. We

497   found that colour-blind and non-colour-blind men showed a high degree of similarity in colour-

498   emotion associations, whether associating colour terms or colour patches. In case of colour

499   patches, the two groups named colours almost identically. Furthermore, the strength of colour

500   blindness neither predicted colour-emotion associations nor emotion intensities. Within group

501   comparisons showed highly similar emotion associations with terms and patches (see also

502   Jonauskaite et al., 2020b), with yet a higher similarity found in non-colour-blind than colour-

503   blind men.

504   Before discussing these major findings, we highlight that we tested representative samples. We

505   replicated common colour-emotion associations such as *red-love, red-anger, yellow-joy, pink-*

506   *love,* and *brown-disgust* associations (Kaya & Epps, 2004; Fugate & Franco, 2019; Jonauskaite

507   et al., 2019a, 2020a). When we clustered the 20 emotion concepts into the affective dimensions

508   of valence, arousal, and power, we replicated that *black*, *grey*, and *brown* were negative colours;

509   *yellow*, *orange*, *blue*, *turquoise*, *pink*, and *white* were positive colours; and *red* was an arousing

510   and powerful colour associated with both positive and negative emotions (Adams & Osgood,

511   1973; Valdez & Mehrabian, 1994; Soriano & Valenzuela, 2009; Lakens, Semin & Foroni, 2012;

512   Sutton & Altarriba, 2016; Specker et al., 2018; Jonauskaite et al., 2020b). These colour-emotion

513   associations were endorsed by both colour-blind and non-colour-blind men.

514   When returning to our major findings, we have to first remember that colour-blind individuals

515   perceive colours differently from non-colour-blind individuals since birth (Linhares, Pinto &

516   Nascimento, 2008). They have diminished or completely absent excitations of the L or M

517   photoreceptors (Dalton, 1798; Parry, 2015). Second, we have to remember that colour-blind

518   individuals have learned the same conceptual representations of colour as non-colour-blind

519   individuals (Byrne & Hilbert, 2010), including colour naming (Bonnardel, 2006, and the current

520   study). With these pieces of information in mind, we can start considering what it might mean

521   that our colour-blind and non-colour-blind participants provided highly similar colour-emotion

522   associations, despite partially different perceptual experiences. First of all, participants likely

523   activated similar abstract colour representations when reading a colour term (e.g., *red*) to when

524   looking at the actual colour patch. Then, we can also consider that the colour-emotion

525   associations were more majorly driven by the conceptual representations of colours, because

526   seeing actual colour patches seemed to carry no additional information to colour-emotion

527   associations (see also, Jonauskaite et al., 2020b). The latter consideration echoes analogue

528   notions for colour-tone associations (Saysani, 2019), transmission of colour terms (Xu, Dowman

529   & Griffiths, 2013), mental colour spaces (Shepard & Cooper, 1992; Saysani, Corballis &

530   Corballis, 2018a,b), or object-colour knowledge (Wang et al., 2020). So far, we have to limit our

531   reasoning to colour-emotion associations for focal colours, which we presented here, and which

532   are highly recognisable by colour-blind men (see also, Moreira et al., 2014).

533   So far, we have discussed the high similarities between groups and conditions. However, the

534   degree of similarities fell short of 100%, leaving space for additional variance to be explained.

535   Part of this variance might be random noise, but part might be linked to meaningful individual

536   differences. In this regard, the degree of colour blindness was uninformative; it did not explain

537   colour-emotion associations or emotion intensities. We observed, however, that the similarity of

538   emotion associations with terms and patches was less pronounced for colour-blind than non-

539   colour-blind men. This relatively lower similarity points to a possible influence of actual colour

540   experiences to colour-emotion associations (see also, Saysani et al., 2018b; Shepard & Cooper,

541   1992). One could suggest that colour-blind men as compared to non-colour-blind men were less

542   certain when naming colour patches. This suggestion seems unlikely, however, because colour-

543   blind and non-colour-blind men named the patches of focal colours almost identically.

544   Alternatively, due to perceptual deficiencies, colour-blind men who saw colour patches might

545   have activated slightly different abstract colour representations than colour-blind men who read

546   colour terms, especially for colours affected by colour blindness. We found that colour-blind

547   men showed the lowest patch-term similarities for *purple* and *green,* and associated more intense

548   emotion concepts with *red*, *orange*, *yellow*, *pink*, *black*, and *white* when colours were presented

549   as terms than patches (see also Jonauskaite et al., 2020b for stronger emotion intensities with

550   terms than patches). Also, colour-blind men associated fewer emotion concepts with *red* than

551   non-colour-blind men. Colour-blind men might have imagined these colours more vividly than

552   seen in patches, associating more intense and specific emotions when processing these terms.

553   Overall, our observations on high degrees of similarities support the previous literature, showing

554   high similarities in colour-emotion associations across cultures (Adams & Osgood, 1973;

555   D'Andrade & Egan, 1974; Gao et al., 2007; Ou et al., 2018; Jonauskaite et al., 2019c, 2020a). At

556   the same time, studies have also shown systematic variations on long-term and short-term scales.

557   On long-term scales, high similarities in colour-emotion associations were more pronounced

558   when individuals came from nations that were linguistically and/or geographically closer

559   (Jonauskaite et al., 2020a). For instance, individuals living closer to the equator had a lower

560   likelihood to associate *yellow* with *joy* than individuals living further away from the equator

561   (Jonauskaite et al., 2019a). Studies have also shown systematic variations on shorter time scales.

562   Individuals living in the same nation preferred autumn-like colours more strongly in autumn than

563   during other seasons of the year (Schloss & Heck, 2017; Schloss et al., 2017). On even shorter

564 time scales, colour preferences have been influenced in a laboratory experiment (Strauss, Schloss

565 & Palmer, 2013). These authors showed that exposure to numerous positive objects (e.g.,

566 strawberries and wine) increased the liking of the respective colour (e.g., *red*), while exposure to

567 numerous negative objects (e.g., a bloody nose and rotten tomatoes) decreased the liking of the

568 respective colour (e.g., *red*). Likely, studies showing such systematic variations demonstrate the

569 human species' abilities to adapt to particularities of their respective environments (Lupyan &

570 Dale, 2016).

571 As an auxiliary finding, we observed a low similarity in emotion associations with *purple*. We

572 observed dissimilar associations between colour-blind and non-colour-blind men as well as

573 between terms and patches in colour-blind men. Colour-blind men associated *purple* with diverse

574 positive as well as negative emotions, while non-colour-blind men associated *purple*, especially

575 as a term, with positive emotions, mainly with *love*. Diverse findings for *purple* are not new.

576 Participants in general disagree which emotions *purple* represent, whether data originate from

577 the same nation (Wexner, 1954; Hemphill, 1996; Sandford, 2014; Sutton & Altarriba, 2016;

578 Fugate & Franco, 2019), from four or 30 nations (Hupka et al., 1997; Jonauskaite et al., 2020a),

579 or when comparing terms and patches (Jonauskaite et al., 2020b), as was also done here. We

580 suggest that this lack of clarity for *purple* is an interesting observation, so much so that it

581 deserves its own investigation (e.g., Hamilton, 2014; Oja & Uusküla, 2011; Tager, 2018).

582 *4.2.*   *Strengths and Limitations*

583 There are numerous strengths and limitations to our study. The first strength is that we employed

584 the same method used previously to assess colour-emotion associations (Griber, Jonauskaite &

585 Mohr, 2019; Jonauskaite et al., 2019a,b,c, 2020a,b). This consistency simplifies direct

586 comparisons between studies. The second strength is that we recruited a large number of

587 congenitally colour-blind men, at least when comparing our sample size to previous studies

588 (Shepard & Cooper, 1992; Paramei, 1996; Paramei, Bimler & Cavonius, 1998; Bonnardel, 2006;

589 Moreira et al., 2014; Álvaro et al., 2015, 2017; Sato & Inoue, 2016; Saysani, Corballis &

590 Corballis, 2018a). By default, a larger sample size provides more representative colour-emotion

591 associations. Yet, having a larger sample size for our colour-blind men also meant that our

592 sample was relatively diverse (see also Bonnardel, 2006; Nagy et al., 2014; Paramei, 1996). We

593 recruited all men who had self-reported congenital red-green colour blindness, irrespective of its

594 strength. Thus, we tested men with partial as well as complete colour vision deficiencies (i.e.,

595 dichromatic and anomalous trichromatic vision), with mainly deutan-like or unidentified

596 impairments. Only some previous studies aimed for a sample of exclusively dichromatic

597 participants (e.g., Álvaro et al., 2015, 2017; Moreira et al., 2014; Shepard & Cooper, 1992),

598 resulting in a much smaller number of tested individuals.

599 To factor in this diversity and to account for varying strength of colour blindness, we derived the

600 Colour Blindness Index from scores on three behavioural colour vision tests (Farnsworth, 1947;

601 Lanthony, 1978b; Ishihara, 2000). This Colour Blindness Index was not a significant predictor of

602 colour-emotion associations, while between- as well as within-group similarities were high.

603 Therefore, we argue that differences in colour perception within our colour-blind group bore

604 little relevance to colour-emotion associations, at least when working with highly recognisable

605 focal colours. If this conclusion holds true, similar colour-emotion associations should also arise

606 in congenitally blind individuals. Previous studies have demonstrated that congenitally blind

607 individuals possess similar mental spaces of colour (Saysani, Corballis & Corballis, 2018b),

608   associate similar colours with pure tones (Saysani, 2019), and represent object-colour knowledge

609   in similar brain regions as sighted individuals (Wang et al., 2020).

610   Another potential limitation is the use of focal colours (i.e., best examples of colour categories)

611   and basic colour terms, both of which are overlearned. Testing colour patches that are difficult to

612   name or using non-basic colour terms, like *lavender* or *mauve*, would be the next step in this type

613   of research. Such colour stimuli might be more powerful to reveal more differences between

614   colour-blind and non-colour-blind individuals. The perceptual experience might be more

615   important when working with stimuli that are less overlearned. In a previous study (Saysani,

616   Corballis & Corballis, 2018a), the mental arrangement of non-basic colour terms was less similar

617   between colour-blind and non-colour-blind individuals than the mental arrangement of the basic

618   colour terms. Yet, the similarity between the two groups was still very high in both conditions,

619   suggesting that colour-blind participants have a common understanding of non-basic colour

620   terms too.

621   *4.3.   Theoretical and Practical Implications*

622   All results considered, we conclude that cultural knowledge, transmitted through language, plays

623   a sufficient role for colour-emotion associations to occur, while immediate perceptual colour

624   experience in adulthood does not seem to be necessary. This conclusion has implications to

625   theories in which the importance of colour perception to affective associations with colour is

626   highlighted (Hurlbert & Ling, 2007; Palmer & Schloss, 2010; Schloss, 2018). According to the

627   cone-opponent theory (Hurlbert & Ling, 2007), human colour preferences are influenced by

628   weights on the two cone-opponent contrast components (i.e., L-M; S-(L+M)). According to the

629   Ecological Valence Theory (Palmer & Schloss, 2010), human colour preferences are driven by

630   the valence of objects of the same colour. For instance, people like colours that are associated

631   with positive objects and dislike colours that are associated with negative objects. As an

632   example, *blue* would be liked because it is associated with clear sky and clean water while *brown*

633   would be disliked because it is associated with rotten food. Note, these theories have been

634   developed to explain colour preferences and not colour-emotion associations (but see Schloss,

635   2018). Perhaps, colour preferences and colour-emotion associations are guided by different

636   mechanisms. In fact, colour preferences have been hypothesised (Schloss, 2015) and empirically

637   demonstrated (Álvaro et al., 2015; Baek et al., 2015; Sato & Inoue, 2016) to differ between

638   colour-blind and non-colour-blind individuals. More specifically, colour-blind individuals

639   preferred *yellowish* colours to a greater extent and *bluish* colours to a lesser extent than non-

640   colour-blind individuals (Álvaro et al., 2015). Colour preferences seem also less universal

641   (Taylor, Clifford & Franklin, 2013; Schloss & Palmer, 2017; Groyecka et al., 2019). Thus,

642   immediate perceptual experiences might be more relevant to colour preferences than to colour-

643   emotion associations. Alternatively, future theories should account for more conceptual,

644   knowledge- and language-based factors when explaining colour preferences (see Yokosawa et

645   al., 2016 for the importance of symbolic colour associations to colour preferences).

646   If immediate perceptual experiences are not necessary for colour-emotion associations in

647   adulthood, then research on colour-emotion associations might not easily translate to applied

648   domains. For instance, proponents of colour therapy, or chromotherapy, assume that perception

649   of colour can impact one's affective states (Azeemi & Raza, 2005; O'Connor, 2011; Winkler,

650   2012; Gul, Nadeem & Aslam, 2015). Often, such claims are based on conceptual colour

651   associations. One can read, "Being the lightest hue of the spectrum, the colour psychology of

652   yellow is uplifting and illuminating, offering hope, happiness, cheerfulness and fun" (Scott-

653   Kemmis, 2018). *Yellow* was indeed conceptually associated with *joy* in 55 countries (Jonauskaite

654   et al., 2019a). However, an association between *yellow* and *joy* does not immediately imply that

655   looking at *yellow* walls or *yellow* objects would make one feel *joyful*. Empirical studies have

656   struggled to confirm many of the expected psychological effects of colour, such as *pink* reducing

657   aggressiveness in prisoners (Genschow et al., 2015), or *pink*, *red*, or *blue* enhancing cognitive

658   performance and improving mood (von Castell et al., 2018). A recent study also demonstrated

659   that direct exposure to colour was not important to stress and anxiety reduction following a

660   colour intervention (Jonauskaite et al., 2020c). In short, conceptual colour-emotion associations

661   should not be equated with and might not translate to psychological consequences of colour.

662   **5. Conclusions**

663   We evaluated whether conceptual mechanisms are sufficient for consistent colour-emotion

664   associations to emerge or whether immediate colour experience is necessary We found that

665   colour-emotion associations were highly similar between individuals with congenital red-green

666   colour blindness and individuals with intact colour vision. This high similarity was observed

667   whether colours were shown as terms or patches. Based on our findings, we conjecture that intact

668   immediate colour vision is not necessary for colour-emotion associations, at least not in

669   adulthood. Likely, these associations are driven by conceptual mechanisms, our language and

670   knowledge. In other words, it is unlikely that colour-emotion associations arise exclusively from

671   direct affective experiences when seeing colours, because conceptual knowledge is already well

672   established. To reason one step further, high similarities between colour-blind and non-colour-

673   blind individuals as well as similarities across cultures (Adams & Osgood, 1973; Jonauskaite et

674 al., 2020a) would suggest that colour-emotion associations present another human psychological

675 universal (Norenzayan & Heine, 2005).

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679 **7. References**

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Figure 1

Geneva Emotion Wheel (GEW) to assess colour-emotion associations with colour terms and colour patches.

The intensity of the associated emotions was assessed with circles of increasing size, smaller circles indicated less intense emotions. See Table S 1. for the French version (Scherer, 2005; Scherer et al., 2013).

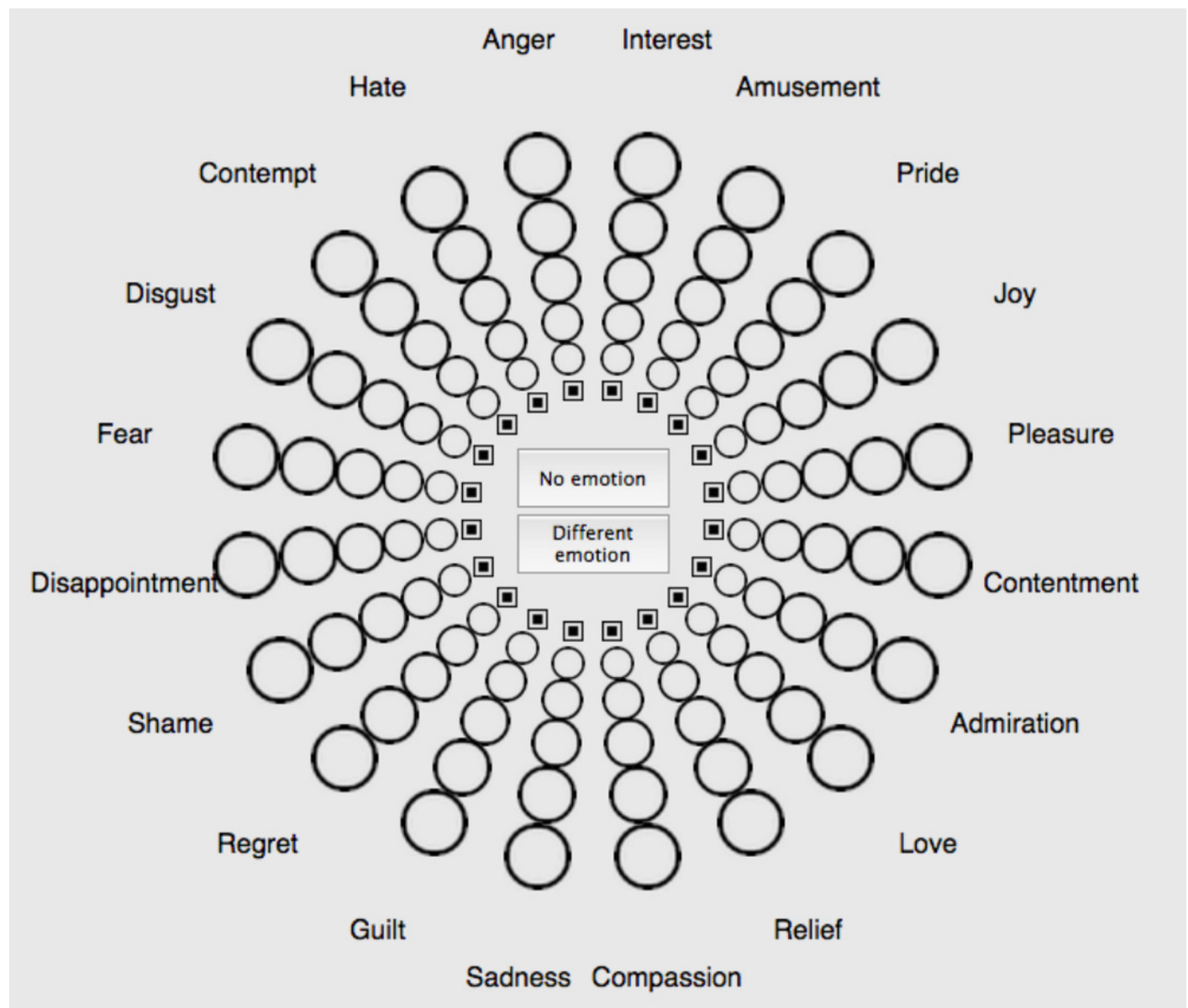



Figure 2

Procedure for the colour terms and colour patches conditions.

(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 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.

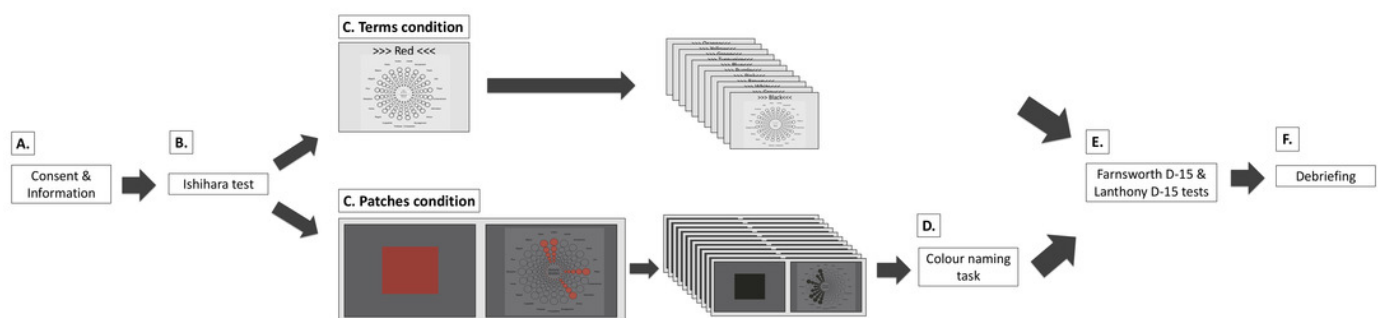
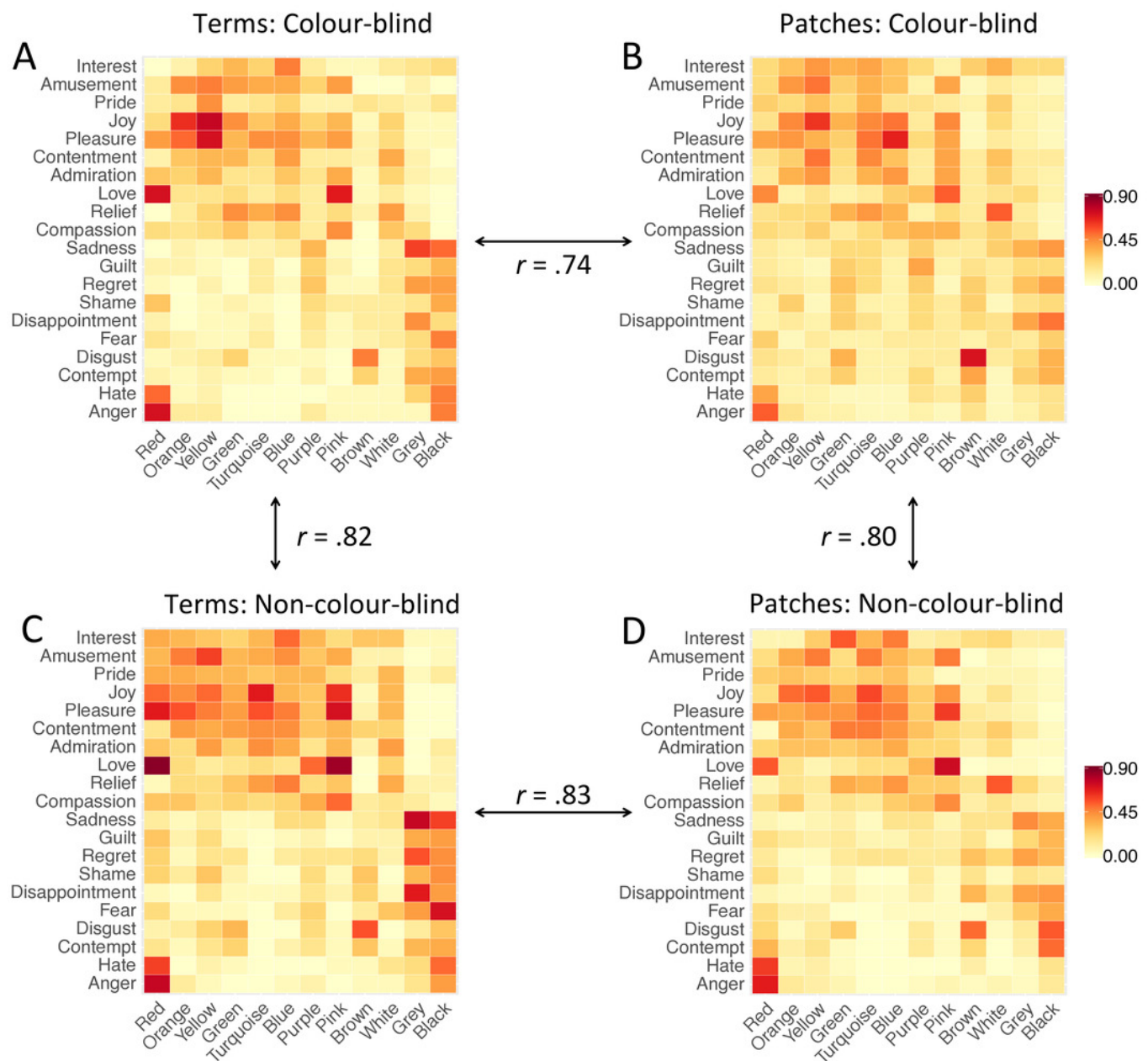



Figure 3

Heatmaps of colour-emotion associations

(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.

Demographic information of colour-blind and non-colour-blind participants, divided by condition

1   **Table 1. Demographic information of the colour-blind and non-colour-blind participants, divided by**
2   **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

Colour stimuli used in the terms and patches conditions.

Munsell values for colour patches taken from Lindsey & Brown (2014). The last columns show the CIE1931 *xyY* values for our patches.

1 **Table 2. Colour stimuli used in the terms and patches conditions.** Munsell values for colour patches taken
2 from Lindsey & Brown (2014). The last columns show the CIE1931 *xyY* values for our patches.

Colour term	Colour patch					
	Munsell colour-order system			CIE1931 coordinates		
	Hue	Value	Chroma	Y (cd/m²)	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

Matrix-to-matrix correlations per colour (PSI$_{colour}$), 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.

1   **Table 3. Matrix-to-matrix correlations per colour (PSI$_{colour}$), separated by correlations between colour-**
2   **blind and non-colour-blind participant association matrices, and between colour terms and colour**
3   **patches association matrices.** The PSI$_{colour}$ (correlation coefficient *r*) indicates the similarity between two
4   matrices with 1 indicating perfect similarity. All *p*-values are FDR corrected for multiple comparisons; * *p*
5   < .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**