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ARTICLE

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A comparative analysis of colour–emotion associations in 16–88-year-old adults from 31 countries

Domicele Jonauskaite[1,2] | Déborah Epicoco[1] | Abdulrahman S. Al-rasheed[3] | John Jamir Benzon R. Aruta[4] | Victoria Bogushevskaya[5] | Sanne G. Brederoo[6] | Violeta Corona[7,8] | Sergejs Fomins[9] | Alena Gizdic[10] | Yulia A. Griber[11] | Jelena Havelka[12] | Marco Hirnstein[13] | George John[14] | Daniela S. Jopp[15] | Bodil Karlsson[16] | Nikos Konstantinou[17] | Éric Laurent[18] | Lynn Marquardt[19] | Philip C. Mefoh[20] | Daniel Oberfeld[21] | Marietta Papadatou-Pastou[22] | Corinna M. Perchtold-Stefan[23] | Giulia F. M. Spagnulo[1] | Aygun Sultanova[24] | Takumi Tanaka[25] | Ma. Criselda Tengco-Pacquing[26] | Mari Uusküla[27] | Grażyna Wąsowicz[28] | Christine Mohr[1]

Correspondence
Domicele Jonauskaite, Institute of Psychology, University of Lausanne, CH-1015 Lausanne, Switzerland.
Email: domicele.jonauskaite@unil.ch

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Abstract
As people age, they tend to spend more time indoors, and the colours in their surroundings may significantly impact their mood and overall well-being. However, there is a lack of empirical evidence to provide informed guidance on colour choices, irrespective of age group. To work towards informed choices, we investigated whether the associations between colours and emotions observed in younger individuals also apply to older adults. We recruited 7393 participants, aged between 16 and 88 years and coming from 31 countries. Each participant associated 12 colour terms with 20 emotion concepts and rated the intensity of each associated emotion. Different age groups exhibited highly similar patterns of colour–emotion associations (average similarity coefficient of .97), with subtle yet meaningful age-related differences. Adolescents associated the greatest number

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but the least positively biased emotions with colours. Older participants associated a smaller number but more intense and more positive emotions with all colour terms, displaying a positivity effect. Age also predicted arousal and power biases, varying by colour. Findings suggest parallels in colour–emotion associations between younger and older adults, with subtle but significant age-related variations. Future studies should next assess whether colour–emotion associations reflect what people actually feel when exposed to colour.

KEYWORDS

affect, ageing, colour, cross-cultural psychology, cross-modal correspondences, development, perception

BACKGROUND

Colours carry affective meanings across languages and cultures. For instance, English speakers would say they *feel blue* when they are sad, while German speakers would say they *are blue* when they are drunk. Despite such differences, colour–emotion associations are surprisingly consistent across countries (Adams & Osgood, 1973; Hupka et al., 1997; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Wicker, et al., 2019; Madden et al., 2000; Ou et al., 2018; Uusküla et al., 2023). Examples of widely shared associations include associations between red and anger, red and love, pink and love, white and relief, grey and sadness, black and sadness and black and fear (Fugate & Franco, 2019; Hanada, 2018; Jonauskaite, Abu-Akel, et al., 2020; Kaya & Epps, 2004). Likewise, lighter and brighter colours are consistently associated with more positive emotions, darker and desaturated colours with more negative emotions and darker and more saturated colours with more arousing emotions (Adams & Osgood, 1973; Jonauskaite, Parraga, et al., 2020; Specker et al., 2018; Valdez & Mehrabian, 1994). Beyond widely shared associations, there are some modulations due to linguistic or geographic factors. For instance, participants living closer to the equator, and especially in dryer countries, associated yellow with joy to a lower extent than those living in rainier and colder countries (Jonauskaite, Abdel-Khalek, et al., 2019).

An important shortcoming of the colour–emotion research to date is that most of the previous findings originate from young adults, ignoring physiological, cognitive, affective and experiential changes that can come with age (see reviews on developmental and age-related functional changes; Barbur & Rodriguez-Carmona, 2015; Charles & Carstensen, 2010; Delcampo-Carda et al., 2019; Drag & Bieliauskas, 2010; Griber et al., 2020; Maule et al., 2023; Owsley, 2016). Especially noteworthy are age-related changes in the sensory domain, including reduction in visual capacity due to life-long use of key eye structures and eye diseases such as glaucoma or macular degeneration (Barbur & Rodriguez-Carmona, 2015). Some more recent research also points to potential age-related changes in the experience and the processing of emotions (Charles & Carstensen, 2010). Then, a very common health issue, particularly in very old age, is reduced physical mobility. And so, staying in the same-coloured environment over prolonged periods of time might bear on individuals' functioning and well-being, both positively and negatively (Torres et al., 2020).

However, before being able to investigate such applied questions, basic assumptions must be verified. One such assumption is that the empirical evidence on the colour–emotion associations obtained with younger individuals is comparable to older adults. While there are large surveys investigating colour–emotion associations systematically across cultures (e.g., Adams & Osgood, 1973; Jonauskaite, Abdel-Khalek, et al., 2019; Jonauskaite, Abu-Akel, et al., 2020; Ou et al., 2018; Uusküla et al., 2023), baseline knowledge on similarities or discrepancies across different age groups is still missing. Thus, in the current study, we elaborated on potential age-related differences in colour–emotion associations.

Very few studies have focused on age-related differences in colour–emotion associations. In Ou and colleagues' study (2012), 20 participants in their 20s and 20 participants in their 60s, all from Taiwan, rated samples of colours on scales opposing warm-cool, heavy-light, active-passive and like–dislike. Only the active-passive scale is informative for colour–emotion associations, likely representing emotional arousal. Both older and younger participants rated red, orange and yellow hues as most active and green and blue hues as least active. Also, both older and younger participants rated more chromatic colour samples as more active than less chromatic samples. Only younger participants also rated lighter colour samples as more active than darker colour samples. In fact, across all colour samples, older participants rated samples as less active than younger participants. In another large-scale multi-nation study (Jonauskaite, Abu-Akel, et al., 2020), there was a U-shape relationship between the number of colour–emotion associations and age. Specifically, the 50–60-year-old group associated the smallest number of emotions while older as well as younger participants associated a slightly larger number of emotions with any colour. In the same study, participants over 70 years old produced the least similar pattern of colour–emotion associations compared to the remaining participants.

To contextualize the evidence and to anticipate further age-related changes in colour–emotion associations, the literature on age-related changes in visual and affective types of processing may be informative. For visual processing, studies showed that chromatic sensitivity decreases from the age of 20 years onwards (Paramei & Oakley, 2014) due to a decrease in retinal ganglion cell axons (Barbur & Rodriguez-Carmona, 2015). Also, from the age of 40–50 years old onwards, individuals find it increasingly difficult to discriminate colours along the yellow–blue axis due to lens brunescence (i.e., yellowing and opaqueness of the lens; Weale, 1988). That said, subjective colour perception seems little affected by ageing due to colour constancy, which acts as a compensation mechanism (Werner, 1996; Wuerger, 2013). In other words, as lens brunescence happens gradually over the years, individuals have time to adapt to their new perceptual realities, and so, subjectively, they do not perceive colours to be yellower (Hardy et al., 2005).

For affective processing, older individuals show a positivity effect (Carstensen & DeLiema, 2018; Reed & Carstensen, 2012), which has been shown both cross-sectionally (Carstensen et al., 2000; Mroczek & Kolarz, 1998), cross-culturally (Kwon et al., 2009) and longitudinally, with studies spanning over 23 years of participant lives (Charles et al., 2001). This effect reliably manifests in diverse cognitive functions, such as selectively remembering positive rather than negative events (Reed et al., 2014). It also applies to emotion-regulation strategies in general (e.g., Boerner & Jopp, 2007; Uittenhove et al., 2023) and when facing negative experiences, including prolonged health-related challenges (Carstensen et al., 2020; Puente-Martínez et al., 2021). Other studies showed that older adults experience more positive than negative emotions and have overall higher life satisfaction than younger adults (Drag & Bieliauskas, 2010). Even very old adults continue having high levels of happiness (Jopp & Rott, 2006). Considering how widely spread this positivity effect is, it might also emerge for colour–emotion associations. However, predicting cross-cultural effects is challenging because the age-related positivity effect further interacts with social and cultural factors (Grossmann et al., 2014; Jebb et al., 2020; Kwon et al., 2009; Lawrie et al., 2020).

To test colour–emotion associations across adulthood and into old age, we used cross-sectional data from the ongoing International Colour–Emotion Association Survey (Jonauskaite, Abu-Akel, et al., 2020; Mohr et al., 2018). In this survey, participants are asked to associate 12 colour categories (colour terms) with 20 emotion concepts. Most previous studies concentrated on university students. To complement these data, we focussed our data collection efforts on colour–emotion associations in adults beyond the common age range of student populations. Thus, the overall sample ranged from 16 to 88 years old. Participants came from 31 countries (see Figure 1) and completed the survey in their native language (22 languages were used in this study). We analysed the associations for the 20 emotion concepts (i) as separate emotion categories, (ii) by counting the total number of associated emotions, (iii) by analysing the intensity of all associated emotions and (iv) by grouping emotions by valence, arousal and power (also known as dominance or potency; see groupings in Fontaine et al., 2007; Jonauskaite, Parraga, et al., 2020).

Based on the age-related changes in the visual system (Barbur & Rodriguez-Carmona, 2015; Owsley, 2016), we expected some age-related differences in colour–emotion associations, likely observable along the yellow-blue axis. However, we expected such effects to be small due to the compensatory

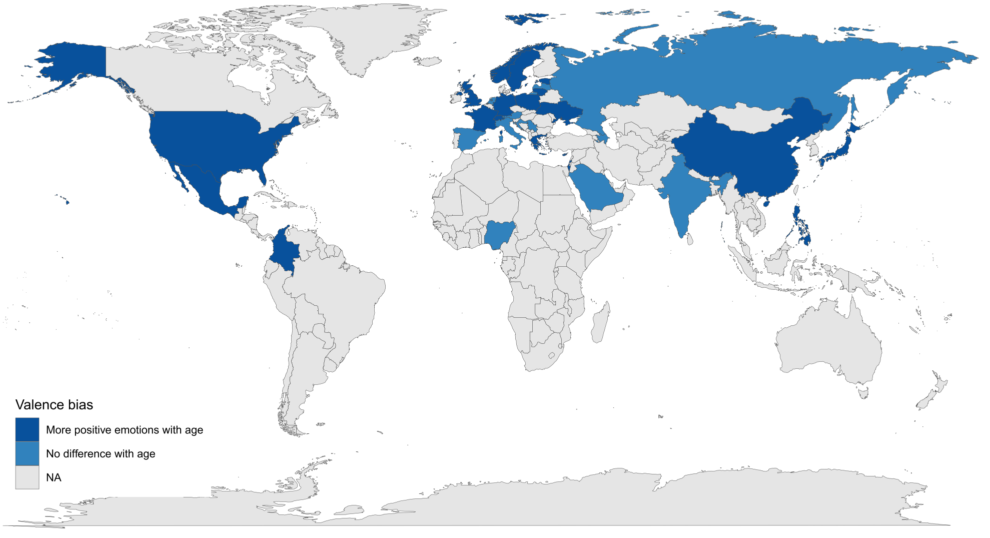

FIGURE 1 The world map of the studied countries, coloured by the presence of the age effect on valence bias. In dark blue countries, older participants associated more positive emotions with colours ($p < .050$), whereas in light blue countries, this was not the case. Grey countries (NA) were not included in the study.

colour constancy mechanism (Hardy et al., 2005). Based on the positivity effect (Reed et al., 2014), we expected older participants to associate colours with more positive emotions than younger participants (i.e., show a positive valence bias). Based on two previous studies (Jonauskaite, Abu-Akel, et al., 2020; Ou et al., 2012), older participants might associate fewer and less arousing emotions with colours than younger participants. We also tested if age-related differences depended on the rated colour (in analogy to Ou et al., 2012). Finally, we used this extensive dataset to verify whether age-related differences were comparable across the 31 studied countries (Adams & Osgood, 1973; Jonauskaite, Abu-Akel, et al., 2020).

METHOD

Participants

We extracted a dataset of 7393 participants from the ongoing International Colour–Emotion Association Survey. Participants came from 31 countries (1881 men, 5465 women, 1734 participants 50 years old or older, mean age = 35.90 years, age range = 16–88 years; see Table 1). The sample sizes ranged from 74 participants (Croatia) to 595 participants (Greece; see Table 1 for further details). In each country, there were at least 25 participants aged 50 years old or older.

Participants had completed the survey in their native language, apart from those being from India, the Philippines and Nigeria, who completed the survey in English. English is the official language in these countries, and participants indicated being fluent in English (self-reported mean fluency rating of 6.98 out of 8). For most analyses, we considered age as a continuous variable, but for some analyses, we separated our participants into age groups. We created a group of adolescents (16–19 years) and six groups of adults, with the oldest group spanning over two decades (70–89 years old; see Table 2). We decided on this age range because, overall, there were very few participants over the age of 80 ($n = 25$; 0.3% of the sample). Moreover, in 15 countries, we had no participants older than 79 (see Age Range in Table 1). We did not collect information on participants' ethnicity, sexual orientation, socio-economic or disability statuses.

Participation was voluntary. 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 Research Ethics Commission of the University of Lausanne (C_SSP_032020_00003). Forty-six per cent

TABLE 1 Demographic information, separated by country of origin.

				Gender		Age (in years)		
Country of origin	**Language**	***N***	***n* (age ≥50 years old)**	**% men**	**% women**	**Mean**	***SD***	**Range**
Austria	German	187	44	17.11	81.28	34.53	15.47	18–71
Azerbaijan	Azerbaijani	379	80	26.65	73.35	36.41	13.82	17–70
China	Chinese	205	35	29.27	70.24	32.40	17.29	17–80
Colombia	Spanish	103	26	41.75	58.25	35.93	14.99	18–74
Croatia	Croatian	74	25	16.22	83.78	38.82	12.94	18–60
Cyprus	Greek	264	34	23.86	76.14	30.11	13.91	16–85
Estonia	Estonian	272	47	10.29	89.71	39.24	11.50	18–70
France	French	241	61	28.63	70.12	36.79	15.78	17–76
Germany	German	443	96	18.96	80.81	35.79	15.37	16–83
Greece	Greek	595	51	17.14	82.52	30.27	10.66	16–76
India	English	103	34	35.92	64.08	38.43	18.61	17–73
Israel	Hebrew	97	35	15.46	84.54	43.40	14.18	21–82
Italy	Italian	165	46	32.12	67.88	38.89	16.39	19–80
Japan	Japanese	147	52	53.06	44.22	41.67	13.82	17–76
Latvia	Latvian	167	36	18.56	80.24	38.61	13.84	19–83
Lithuania	Lithuanian	205	55	17.07	82.93	38.29	14.37	16–80
Mexico	Spanish	362	124	33.43	66.30	39.50	18.89	16–88
Netherlands	Dutch	95	41	35.79	64.21	42.88	18.03	17–84
Nigeria	English	132	40	44.70	55.30	38.15	12.73	19–65
Norway	Norwegian	392	114	17.35	81.89	39.57	15.02	16–86
Philippines	English	275	64	26.91	70.55	34.12	16.51	18–85
Poland	Polish	296	129	28.04	71.96	43.02	19.48	17–81
Russia	Russian	161	43	37.27	62.11	35.92	16.88	16–78
Saudi Arabia	Arabic	213	36	34.74	64.79	31.81	14.68	16–85
Serbia	Serbian	105	29	22.86	77.14	39.35	16.40	20–78

(Continues)

TABLE 1 (Continued)

Country of origin	Language	*N*	*n* (age ≥50 years old)	Gender		Age (in years)		
				% men	% women	Mean	*SD*	Range
Spain	Spanish	162	26	23.46	75.93	34.33	12.96	19–75
Sweden	Swedish	316	81	15.82	82.59	37.53	14.76	16–82
Switzerland	French	588	53	30.27	69.05	26.08	12.07	16–79
Ukraine	Ukrainian	89	30	16.85	83.15	38.85	22.30	18–87
United Kingdom	English	289	121	29.76	68.51	44.55	16.70	16–77
United States	English	271	46	27.31	71.59	32.20	15.62	16–83
All countries together	All languages	7393	1734	25.44	73.92	35.90	15.81	16–88

Note: Across all countries, 47 participants (0.64%) chose not to report their gender.

TABLE 2 Age and gender information, separated by age group.

		Gender		Age (in years)	
Age group	*n*	% men	% women	Mean	*SD*
16–19 years old	615	20.33	79.02	18.32	0.90
20–29 years old	2902	22.29	76.77	23.43	2.79
30–39 years old	1230	26.18	73.50	34.03	2.88
40–49 years old	912	25.88	73.90	44.45	2.95
50–59 years old	971	30.69	68.38	54.23	2.74
60–69 years old	549	32.06	67.76	63.99	2.72
70–89 years old	214	35.98	64.02	74.50	4.14

Note: 47 participants (0.64%) chose not to report their gender.

of this dataset has been published before, answering different research questions (Jonauskaite, Abdel-Khalek, et al., 2019; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Jonauskaite, Wicker, et al., 2019; Ram et al., 2020; Uusküla et al., 2023). For the current study, we made efforts to recruit older participants so we could analyse the data from an adult lifespan perspective.

Emotion stimuli

We used the Geneva Emotion Wheel (GEW version 3.0; Scherer, 2005; Scherer et al., 2013) to measure associations between colour terms and emotion concepts. The GEW is a self-report research tool to assess the most relevant emotions in a user-friendly way (also see, Tran, 2004). There are 20 emotions, presented in a circular format on the GEW, with similar emotions appearing nearby (Figure 2).

These 20 emotions can be further grouped by their underlying affective dimensions according to valence, arousal and power (see Figure 2). The affective loadings were determined in a previous study, conducted in 34 populations coming from 27 countries, speaking 28 languages (Fontaine et al., 2007, 2013; Soriano et al., 2013). The same loadings have been used previously in colour–emotion research (Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Uusküla et al., 2023).

With our collaborators in the International Colour–Emotion Associations Survey, we translated and back-translated the GEW into 46 languages (see the Acknowledgment list in Jonauskaite, Abu-Akel, et al., 2020, also see https://www.colourexperience.ch/collaborations for the most recent list of collaborators). We here present the GEW emotion terms for the 22 languages reported in this study (Tables S1–S3).

Colour stimuli

We assessed emotion associations with 12 colour terms, glossed in English as *red, orange, yellow, green, turquoise, blue, purple, pink, brown, white, grey* and *black*. Eleven of these colour terms (i.e., all but *turquoise*[1])

[1]In most of the studied languages, there is only one basic term to denote the blue range. In these languages, in addition to using the translation of *blue*, we also used the direct equivalent of the English term *turquoise*. In some languages, however, there are two basic colour terms to denote different areas of the blue range (see empirical evidence in Bimler & Uusküla, 2017). For instance, *goluboj* in Russian, *žydra* in Lithuanian and *yalazio* in Greek (Androulaki et al., 2006; Lange et al., 2017; Morgan, 1993; Paramei, 2005; Uusküla & Bimler, 2016). In these languages, we decided on using both basic terms, instead of the direct translation of the English term *turquoise*. Thus, for the translation of *blue*, we chose the basic term referring to darker shades of blue, and for the translation of *turquoise*, we chose the basic term referring to lighter shades of blue (sky blue, green-blue). We are aware that these colour terms might refer to slightly different shades across languages (Paramei et al., 2018). For the sake of simplicity, we continue referring to this colour category using the English term *turquoise*.

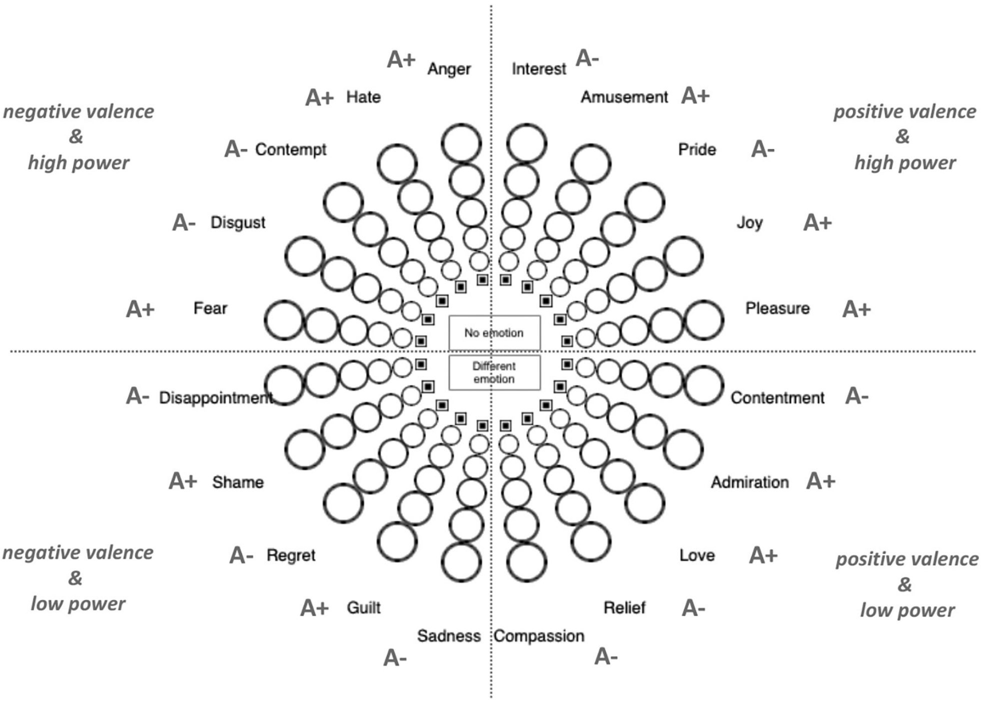

FIGURE 2 Geneva Emotion Wheel (GEW). We used the GEW, adapted from Scherer et al. (2013), to assess associations between colour terms and emotion concepts. We display how each emotion term loads on the affective dimensions of valence, arousal (marked with A+ for high arousal and A− for low arousal) and power (high power and low power). The affective loadings were determined in previous studies (Fontaine et al., 2007, 2013; Scherer et al., 2013) and have been used in previous related studies (Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Uusküla et al., 2023). Participants did not see the dotted lines or the affective loadings.

are basic in Indo-European languages and in many other language families (e.g., Berlin & Kay, 1969; Biggam, 2012; Corbett & Davies, 1997; Uusküla, 2006; Uusküla et al., 2012). A basic colour term implies that its meaning is understood by all native speakers of its respective language, and the term cannot be easily categorized under another term (e.g., *lavender* is not a basic colour term since it is a shade of *purple*; Biggam, 2012). As there are more colour terms for warm shades (e.g., *red*, *orange*, *yellow*, *brown*, *pink*) than cool shades (e.g., *blue, green*), we included *turquoise* to have an additional term covering the area of green-blue shades. We opted for the term *turquoise* in English because it has been suggested to be a potential emerging basic colour term (Mylonas & MacDonald, 2015; Zimmer, 1982; Zollinger, 1984). See Tables S4–S6 for the exact colour terms in each language.

Our participants saw the 12 colour terms in their native languages and written in black ink. As we worked with colour terms, participants never saw physical colours corresponding to the colour terms (see studies comparing emotion associations with colour terms and the corresponding focal colours; Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020).

Procedure of the International Colour–Emotion Association Survey

Participants completed the online survey in their native language, when possible (http://www2.unil.ch/onlinepsylab/colour/main.php; see Jonauskaite, Abu-Akel, et al., 2020, for details on the translation procedure). This ongoing survey starts by stating its main goal and providing ethical information, namely that (i) participation is anonymous and strictly confidential, (ii) responses are used for research purposes and its dissemination and (iii) participants can stop the survey at any time without experiencing any consequences.

Afterwards, participants give informed consent by clicking on the 'Let's go' button. Then, the following pages of the survey explain the task and how the GEW works. Here, participants go through a manipulation check making sure they understand the task. More concretely, participants have to correct the faulty responses made by Peter, an imaginary character. Having passed this check, participants see the 12 colour terms (written in black ink on a grey background, see Figure 2) one after the other above the GEW in a randomized order. They are asked to associate the 20 GEW emotion concepts with the given colour terms by selecting one, several or none of the GEW emotions that they think are associated with each colour term. In this survey, participants can also indicate non-listed emotion terms for each colour term, called 'other emotion' (not analysed here). When making an association, participants evaluate the emotion intensity for every associated emotion by choosing circles of increasing size on the GEW (see Figure 2). The largest circle translates to the intensity of five and the smallest circle to that of one. When participants choose no emotion, we code it as 0.

After associating the 12 colour terms with emotion concepts, participants reported their demographic information: age, gender, colour vision impairments ('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 in which they completed the 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 email address. On average, our participants took 13.5 min to complete the survey. We prefiltered the data from very quick (<3 min) and very slow (>90 min) responders; thus, the range in the current study was between 3.0 and 89.7 min.

Data preparation and analysis

Our data set consisted of 240 data points per participant (12 colour terms × 20 emotions). We derived several new variables to analyse this complex data set, in analogy to previous studies (see Table 3; Jonauskaite, Abdel-Khalek, et al., 2019; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Dael, et al., 2019; Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Uusküla et al., 2023). When necessary, we controlled for the familywise error, arising from multiple comparisons, with the false discovery rate (FDR) correction (Benjamini & Hochberg, 1995).

Patterns of colour–emotion associations

We created the *patterns of colour–emotion associations* by coding for the presence of each colour–emotion association (see Table 3). More precisely, we gave a value of 1 (association present) to all emotion intensity ratings between 1 and 5. We gave a value of 0 (association absent) when no emotion intensity rating was present. Subsequently, we calculated the proportion of participants in each age group who associated each colour term with each emotion concept. To this end, we split our participants into seven age groups, namely 16–19, 20–29, 30–39, 40–49, 50–59, 60–69 and 70–89 years old. The proportions varied from 0 (no one associated) to 1 (everyone associated). These proportions, calculated for 240 colour–emotion combinations, constituted the pattern of colour–emotion associations.

From this pattern, we identified the most frequent associations. We also correlated the patterns of colour–emotion associations of each age group with the patterns of associations of the remaining groups (global pattern) to establish the degree of overall similarity in these patterns (Pearson correlations). Global patterns were created by calculating the patterns of all age groups apart from the age group in question. In this way, each age group contributed equally to the global pattern. Correlations theoretically varied from −1 (completely opposite patterns) to 0 (no similarity) to 1 (identical). In addition, we performed these correlations for each colour term, separately.

TABLE 3 Dependent variables in this study.

Dependent variable	Description	Possible values
Presence of association	Presence or absence of colour–emotion association	Yes/no (for all 240 colour–emotion associations)
Broadness	The number of emotions participants associated with the colour terms	0–20 (for each colour term)
Emotion intensity	The intensity of each emotion associated with a given colour term	1–5 (for each colour term and only for associated emotions)
Affective bias: valence	Relative bias towards positive (+ values) or negative (− values) emotions	−1 to +1
Affective bias: arousal (also known as activity)	Relative bias towards high arousal (+ values) or low arousal (− values) emotions	−1 to +1
Affective bias: power (also known as dominance or potency)	Relative bias towards high power (+ values) or low power (− values) emotions	−1 to +1

Broadness and emotion intensity

For broadness and emotion intensity (see Table 3), we fitted two analogous linear mixed models (lmer; *lme4* and *afex* R packages; Bates et al., 2015; Kuznetsova et al., 2017; Singmann et al., 2023). Our predictor variables were Age (continuous variable, range = 16–88), Colour (categorical variable with 12 levels) and their two-way interaction. To estimate cultural differences, we also added Country (categorical variable with 31 levels) and the interaction between Country and Age. To limit the complexity of the models and since we had no predictions for the three-way interactions, we did not include three-way interactions in the models. We estimated *p*-values with Kenward-Roger's approximation method, with the *pbkrtest* package (Halekoh & Højsgaard, 2014). We calculated pseudo-R^2 values with the *rcompanion* R package (Mangiafico, 2023).

Formally, the models can be described like this:

$$\text{Broadness} \sim \text{Age} \times \text{Colour} + \text{Age} \times \text{Country} + (1 \mid \text{Participant})$$

$$\text{Emotion intensity} \sim \text{Age} \times \text{Colour} + \text{Age} \times \text{Country} + (1 \mid \text{Participant})$$

To estimate any non-linear effects of age, we additionally ran linear mixed models replacing the linear variable Age with the categorical variable Age Group (see Table 2). In the latter models, we could not include Country since not all countries had enough participants in each age group (see Table 1).

Affective biases: valence, arousal, and power

We calculated the *valence bias* in the following way. First, we counted the number of emotions (n_{total}) that each participant associated with the given colour term. Then, we calculated the number of positive (n_{positive}) and negative (n_{negative}) emotions (see Figure 2) following previous studie (Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020; Uusküla et al., 2023). Finally, we subtracted the number of negative emotions from positive emotions and divided the difference by the total number of associated emotions. Formally, the calculation can be described as such,

$$\text{Valence bias} = \left(n_{\text{positive}} - n_{\text{negative}}\right) / \left(n_{\text{positive}} + n_{\text{negative}}\right).$$

Here, the maximum number of $n_{\text{positive}} = 10$, $n_{\text{negative}} = 10$ and $(n_{\text{positive}} + n_{\text{negative}}) = 20$ emotions (see Figure 2). Thus, the valence bias could vary between −1 and 1. The extreme negative bias (−1) indicates that a participant associated only negative emotions while the extreme positive bias (1) indicates that a participant associated only positive emotions with a given colour term.

In analogy, we calculated *arousal* and *power biases*, by exchanging positive and negative emotions with high and low arousal and with high and low power emotions, respectively (see Figure 2). Formally, the calculation can be described as such

$$\text{Arousal bias} = \left(n_{\text{high arousal}} - n_{\text{low arousal}}\right) / \left(n_{\text{high arousal}} + n_{\text{low arousal}}\right),$$

$$\text{Power bias} = \left(n_{\text{high power}} - n_{\text{low power}}\right) / \left(n_{\text{high power}} + n_{\text{low power}}\right).$$

Arousal bias could vary from −1 and 1, respectively indicating that a participant associated only low arousing or high arousing emotions with a given colour term. Power bias could vary from −1 and 1, respectively indicating that a participant associated only low power or high power emotions with a given colour term.

For valence, arousal and power biases, we fitted analogous linear mixed models to those for broadness and emotion intensity:

$$\text{Valence bias} \sim \text{Age} \times \text{Colour} + \text{Age} \times \text{Country} + \left(1 \mid \text{Participant}\right),$$

$$\text{Arousal bias} \sim \text{Age} \times \text{Colour} + \text{Age} \times \text{Country} + \left(1 \mid \text{Participant}\right),$$

$$\text{Power bias} \sim \text{Age} \times \text{Colour} + \text{Age} \times \text{Country} + \left(1 \mid \text{Participant}\right).$$

We additionally ran analogous linear mixed models to estimate any non-linear effects of age. To that end, we replaced Age with Age Group (see Table 2). In the latter models, we could not include Country since not all countries had enough participants in each age group (see Table 1).

Transparency and openness

We report how we determined our sample size, all data exclusions (if any), all manipulations and all measures in the study. All data and research materials are available at https://osf.io/873df. All data were analysed with R, version 4.2.3 (R Core Team, 2023) and R Studio (Posit team, 2022). The study design and its analysis were not pre-registered.

RESULTS

Based on the global pattern of colour–emotion associations (all age groups together), we identified 14 colour–emotion associations chosen by at least 40% of participants (same criterion as in Jonauskaite, Abu-Akel, et al., 2020). These associations were *red-love* (chosen by 69.2% of all participants), *yellow-joy* (55.7%), *red-anger* (55.2%), *black-sadness* (53.7%), *pink-love* (53.2%), *black-fear* (48.7%), *grey-sadness* (47.7%), *orange-joy* (44.6%), *grey-disappointment* (43.9%), *white-relief* (43.5%), *pink-pleasure* (41.8%), *pink-joy* (41.8%), *black-hate* (41.6%) and *orange-amusement* (41.0%).

After establishing the patterns of colour–emotion associations for each age group separately (Figures 3 and 4), we contrasted each of these group-specific patterns to the global pattern of all the

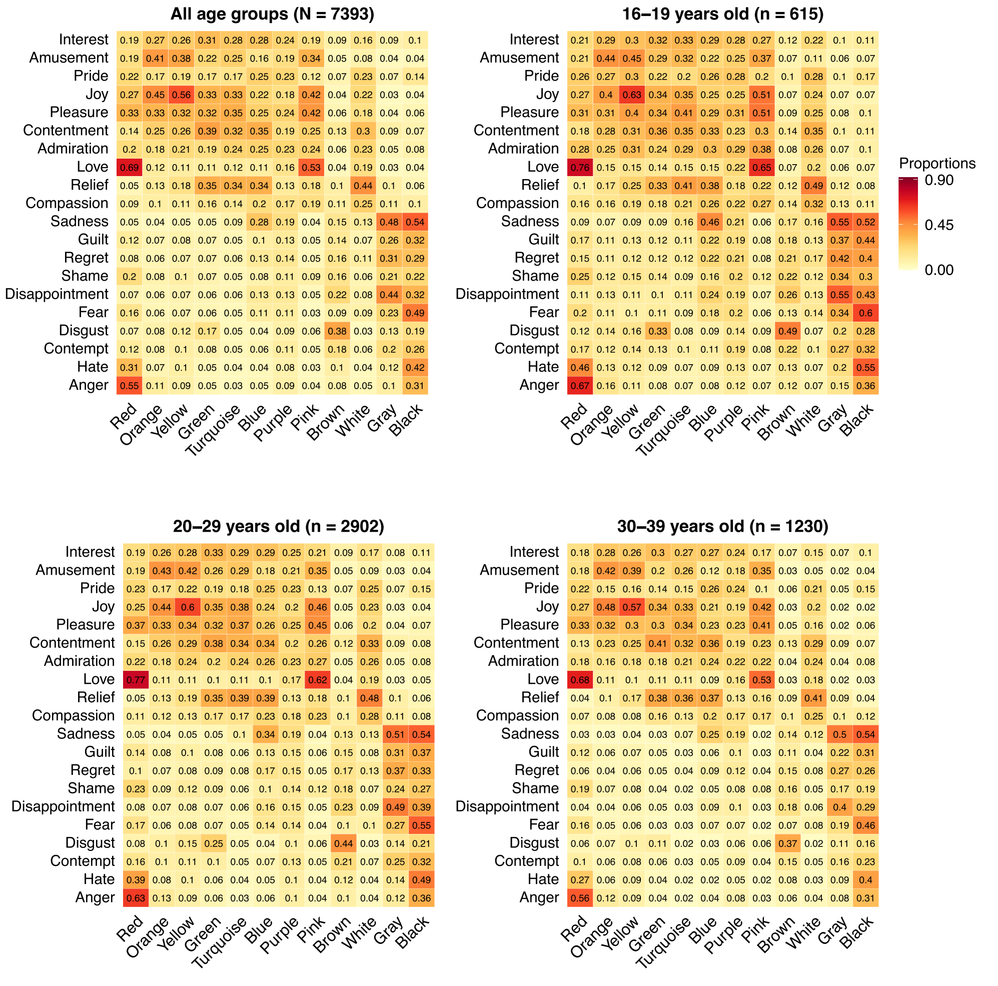

FIGURE 3 Colour–emotion association patterns for all participants together as well as separated by age group (16–19, 20–29 and 30–39 years old; see also Figure 4). Numbers in cells refer to proportions (i.e., the proportion of participants in each group who associated a given colour term with a given emotion term).

other age groups combined. The Pearson correlations were high ($r \geq .934$), indicating a high degree of similarity in the patterns of colour–emotion associations across the age groups (see Table 4). These correlations were also extremely high when looking at each colour term individually, ranging from $r = .931$ (*blue*) to $r = .989$ (*pink*), see Table S7.

The numerically strongest correlation was observed between the colour–emotion association pattern of 30–39-year-olds and the global pattern ($r = .991$; Table 4). We compared all other correlations to the 30–39 age group and reported that 40–49-year-olds had an equally strong correlation. The remaining age groups had significantly lower correlations. The weakest (but still very strong) correlations with the global pattern were those of the youngest and the oldest age groups ($r \geq .935$; Table 4).

Age-related differences in broadness of emotion associations

Participants associated on average 3.29 emotions (95% CI = [3.26, 3.32]) with the 12 colour terms. A linear mixed model predicting broadness from Age, Colour, Country and the two-way interactions between

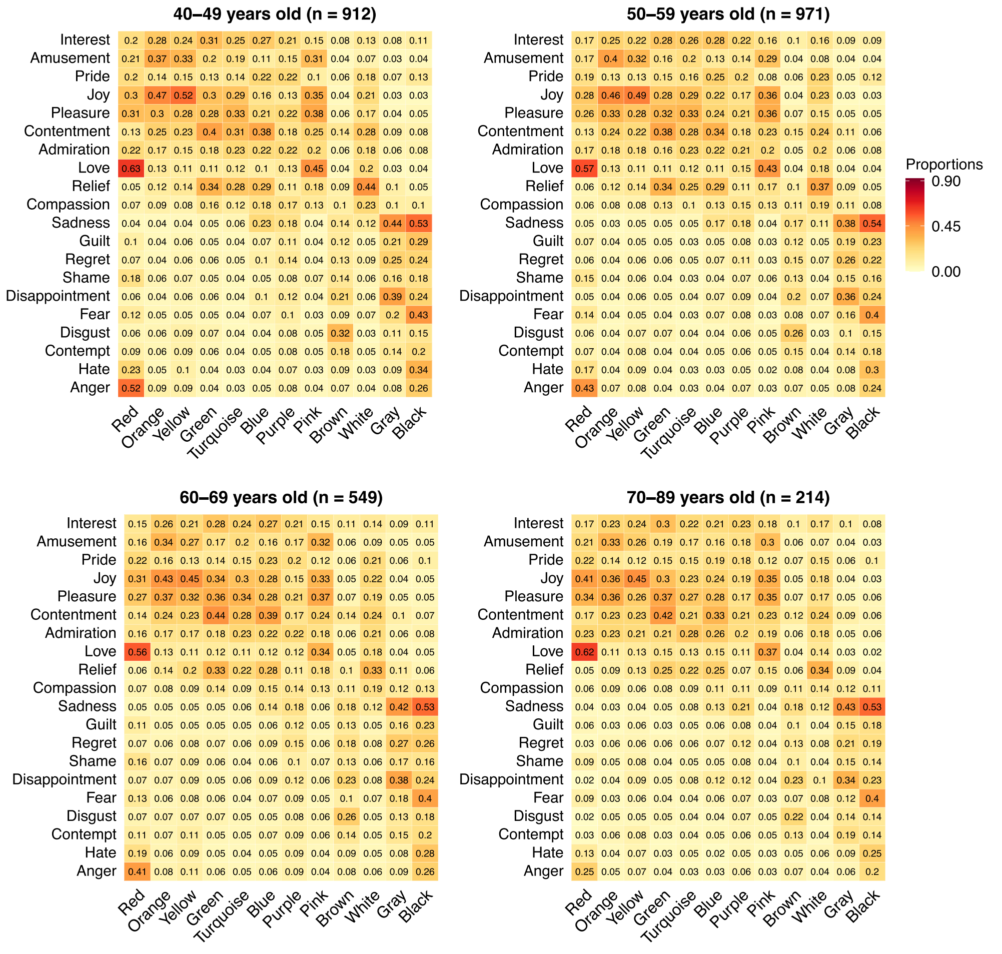

FIGURE 4 Colour–emotion association patterns are separated by age group (40–49, 50–59, 60–69 and 70–89 years old; see also Figure 3). Numbers in cells refer to proportions (i.e., the proportion of participants in each group who associated a given colour term with a given emotion term).

Age and Colour and Age and Country as predictors of broadness was significant, $F(83, 13{,}670) = 82.7$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .073.

The main effect of Age, $F(1, 7554) = 90.0$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .002, suggested that as participants' age increased, broadness decreased. In other words, as participants got older, they associated fewer emotions with colour terms (Figure 5, Table 5). We found a significant two-way interaction between Age and Colour, $F(11, 81{,}286) = 29.9$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .070. As participants got older, they associated fewer emotions with each of the colour terms (see Table 6). We also found a significant two-way interaction between Country and Age, $F(30, 7553) = 2.72$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .004. Age was a significant predictor in 16 countries, in which older participants associated fewer emotions with colour terms (Table 7).

Additionally, the main effect of Colour, $F(11, 81{,}286) = 202.1$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .065, highlighted that broadness values differed by colour term. *Red* had the highest broadness values, whereas *brown* had the lowest broadness values (see Table S8). The main effect of Country, $F(30, 7550) = 3.04$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .002, highlighted that broadness values also differed by country. Participants coming from Japan had the highest broadness values, and participants from Azerbaijan had the lowest broadness values (see Table S10).

TABLE 4 Correlation table between the global matrix of colour–emotion associations (excluding the age group of interest) and the age group of interest; comparison of the strength of correlation with the strongest correlation (30–39 years).

Age group	Pattern similarity index		Comparison with the strongest correlation
	r value	95% CI	*z* value
16–19 years old versus global	.942***	[0.926–0.955]	−10.28***
20–29 years old versus global	.976***	[0.969–0.981]	−5.38***
30–39 years old versus global	.991***	[0.988–0.993]	0
40–49 years old versus global	.989***	[0.986–0.991]	−1.10
50–59 years old versus global	.983***	[0.978–0.987]	−3.48***
60–69 years old versus global	.970***	[0.961–0.976]	−6.61***
70–89 years old versus global	.935***	[0.916–0.949]	−10.92***

Note: Significance coded as such $*p<.050$, $**p<.010$, $***p<.001$.

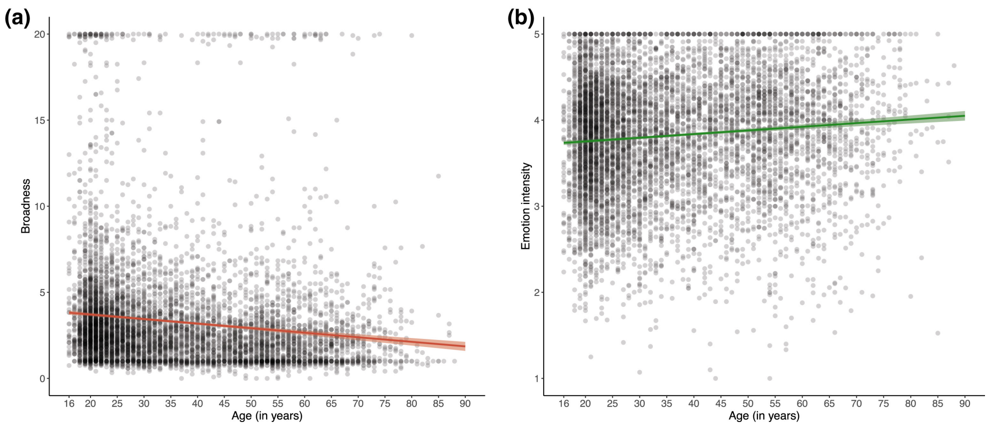

FIGURE 5 Broadness (a) and emotion intensity (b), both predicted by participants' age. Both broadness and emotion intensity variables were averaged across colour terms before plotting. Broadness represents the number of emotions associated with a colour term. It ranges from 0 to 20 emotions. Emotion intensity represents the intensity rating of each emotion associated with a colour term. It ranges from 1 to 5. Each point represents an individual participant.

TABLE 5 Statistics for age as a significant predictor of broadness, emotion intensity and affective biases.

Dependent variables	β	*SD*	*t* value
Broadness	−.42	0.04	−9.48***
Emotion intensity	.09	0.01	9.26***
Valence bias	.04	<0.01	13.68***
Arousal bias	<.01	<0.01	0.46
Power bias	<.01	<0.01	0.33

Note: Significance coded as such $*p \leq .050$, $**p \leq .010$, $***p \leq .001$. Also see Figures 5 and 7 for visual representation of these results.

An additional linear mixed model predicting broadness from Age Group, Colour and a two-way interaction between Age Group and Colour was also significant, $F(83, 86{,}691) = 80.7$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .071. The main effect of Age Group, $F(6, 7697) = 24.7$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .002, indicated that broadness differed across the groups. Deviation planned contrasts revealed that participants aged 16–19 and 20–29 years associated significantly more emotions than did participants from the

TABLE 6 Statistics for age, separated by colour term, predicting broadness, emotion intensity and affective biases (Age × Colour interaction).

	Broadness			Emotion intensity			Valence bias			Arousal bias			Power bias		
Colour term	β	*SD*	*t* value	β	*SD*	*t* value	β	*SD*	*t* value	β	*SD*	*t* value	β	*SD*	*t* value
Red	−.56	0.04	−12.65***	.06	0.01	6.37***	.08	0.01	10.20***	.01	0.01	−0.43	.01	0.01	1.62
Orange	−.29	0.04	−7.08***	.12	0.01	10.62***	.09	0.01	11.22***	.03	0.01	3.26**	.01	0.01	1.91
Yellow	−.47	0.04	−11.38***	.05	0.01	4.81***	.01	0.01	1.36	.02	0.01	2.37*	.01	0.01	1.58
Green	−.34	0.04	−8.24***	.12	0.01	10.85***	.12	0.01	15.18***	.01	0.01	1.07	−.06	0.01	−7.49***
Turquoise	−.40	0.04	−9.76***	.08	0.01	7.08***	.03	0.01	4.49***	.04	0.01	5.21***	.03	0.01	3.74***
Blue	−.46	0.04	−10.80***	.08	0.01	7.65***	.12	0.01	14.25***	.01	0.01	1.25	.05	0.01	6.50***
Purple	−.41	0.04	−9.72***	.10	0.01	8.29***	.03	0.01	2.91**	−.03	0.01	−4.08***	−.03	0.01	−3.33**
Pink	−.46	0.04	−11.30***	.05	0.01	4.66***	.01	0.01	0.93	−.02	0.01	−2.48*	.04	0.01	5.18***
Brown	−.23	0.04	−5.70***	.04	0.01	2.97**	.06	0.01	6.86***	−.01	0.01	−1.70	−.07	0.01	−8.42***
White	−.35	0.04	−8.31***	.05	0.01	3.96***	.02	0.01	2.55*	.03	0.01	3.42**	.03	0.01	3.94***
Grey	−.45	0.04	−11.04***	.03	0.01	2.46*	.07	0.01	8.87***	−.05	0.01	−7.44***	−.03	0.01	−3.93***
Black	−.61	0.04	−14.05***	.04	0.01	3.52***	.03	0.01	3.55***	−.06	0.01	−8.93***	−.05	0.01	−6.24***

Note: Significance coded as such $*p \leq .050$, $**p \leq .010$, $***p \leq .001$. All p-values after FDR correction. Also see Figures 5 and 7 for visual representation of the results.

TABLE 7 Statistics for age, separated by country, predicting broadness, emotion intensity and affective biases (Age × Country interaction).

		Broadness			Emotion intensity			Valence bias			Arousal bias			Power bias		
Country	***n***	***β***	***SD***	***t* value**	***β***	***SD***	***t* value**	***β***	***SD***	***t* value**	***β***	***SD***	***t* value**	***β***	***SD***	***t* value**
Austria	187	.11	0.25	0.45	.04	0.05	0.76	.03	0.02	2.04	−.01	0.01	−0.63	−.01	0.01	−0.87
Azerbaijan	379	−.24	0.11	−2.14	−.03	0.04	−0.84	.03	0.01	2.01	.01	0.01	0.66	.02	0.01	1.37
China	205	−.30	0.22	−1.37	.08	0.04	1.77	.09	0.02	5.40***	<.01	0.01	−0.27	−.03	0.01	−1.98
Colombia	103	−.97	0.35	−2.80*	.15	0.07	2.00	.07	0.02	2.94**	−.01	0.02	−0.56	−.05	0.02	−2.43
Croatia	74	.13	0.57	0.23	.18	0.11	1.64	−.02	0.04	−0.64	−.02	0.03	−0.68	−.04	0.03	−1.51
Cyprus	264	−.70	0.24	−2.88*	.20	0.05	4.21***	.04	0.02	2.36*	−.02	0.01	−1.42	.01	0.01	0.42
Estonia	272	.07	0.27	0.25	.17	0.06	2.96*	.05	0.02	2.29*	−.01	0.02	−0.61	−.05	0.02	−3.27*
France	241	−.29	0.17	−1.69	.07	0.04	1.61	.03	0.01	2.18*	−.02	0.01	−1.70	−.02	0.01	−1.50
Germany	443	−.66	0.14	−4.59***	.14	0.03	4.49***	.03	0.01	3.18**	.01	0.01	1.61	.01	0.01	1.72
Greece	595	−.51	0.18	−2.87*	.07	0.04	1.93	.08	0.02	5.21***	<.01	0.01	−0.02	.01	0.01	0.91
India	103	−.66	0.20	−3.39**	.15	0.05	2.72*	<.01	0.02	−0.04	−.02	0.02	−0.87	.01	0.02	0.70
Israel	97	−.39	0.29	−1.37	.02	0.07	0.31	.09	0.02	4.02***	.06	0.02	2.67	.04	0.02	1.82
Italy	165	−.01	0.22	−0.03	.04	0.05	0.95	−.01	0.01	−0.93	.01	0.01	0.37	.01	0.01	0.38
Japan	147	.29	0.32	0.90	−.04	0.07	−0.61	.07	0.02	3.07**	.05	0.02	3.31*	.05	0.02	3.26*
Latvia	167	.15	0.37	0.40	.05	0.06	0.85	.04	0.02	1.80	−.01	0.02	−0.63	.04	0.02	2.07
Lithuania	205	−.98	0.31	−3.21**	.16	0.05	3.08*	.09	0.02	5.22***	−.03	0.02	−2.33	−.01	0.02	−0.71
Mexico	362	.12	0.17	0.67	.08	0.03	2.95*	.06	0.01	5.34***	<.01	0.01	−0.43	−.02	0.01	−1.92
Netherlands	95	−.77	0.23	−3.37**	.13	0.07	1.90	<.01	0.02	−0.17	−.04	0.02	−2.48	−.04	0.02	−1.92
Nigeria	132	−.42	0.16	−2.65*	.14	0.05	3.05*	.04	0.02	2.00	.03	0.02	1.57	.03	0.02	1.54
Norway	392	−.38	0.15	−2.59*	.05	0.04	1.50	.06	0.01	5.31***	−.02	0.01	−2.23	<.01	0.01	−0.39
Philippines	275	−.72	0.23	−3.16**	.21	0.04	5.75***	.07	0.01	5.62***	.01	0.01	0.91	.01	0.01	1.10
Poland	296	−.25	0.12	−2.16	.13	0.03	3.92***	.04	0.01	3.22**	.00	0.01	0.28	−.02	0.01	−2.33
Russia	161	−.38	0.18	−2.12	.16	0.04	3.72**	.03	0.02	1.64	−.02	0.02	−1.25	−.02	0.02	−1.33
Saudi Arabia	213	−.48	0.24	−1.98	−.01	0.05	−0.19	<.01	0.02	0.27	.04	0.02	2.40	<.01	0.02	−0.16
Serbia	105	−.90	0.32	−2.83*	.15	0.07	2.08	.04	0.02	2.10	.00	0.02	−0.05	−.01	0.02	−0.47

TABLE 7 (Continued)

		Broadness			Emotion intensity			Valence bias			Arousal bias			Power bias		
Country	***n***	***β***	***SD***	***t* value**	***β***	***SD***	***t* value**	***β***	***SD***	***t* value**	***β***	***SD***	***t* value**	***β***	***SD***	***t* value**
Spain	162	−1.10	0.27	−4.17***	.06	0.06	1.01	.04	0.02	2.03	.01	0.02	0.47	−.03	0.02	−1.54
Sweden	316	−1.00	0.19	−5.20***	.10	0.04	2.53*	.06	0.01	4.69***	−.01	0.01	−1.17	<.01	0.01	−0.07
Switzerland	588	−.75	0.18	−4.22***	.04	0.03	1.07	.04	0.01	3.57**	−.02	0.01	−1.86	.00	0.01	0.35
Ukraine	89	−.80	0.34	−2.38*	<.01	0.06	0.00	.06	0.02	3.27**	.01	0.02	0.88	.03	0.02	1.74
United Kingdom	289	−.41	0.15	−2.81*	.02	0.04	0.46	.04	0.01	3.49**	<.01	0.01	0.17	.03	0.01	2.48
United States	271	−.27	0.17	−1.63	−.07	0.04	−1.73	.08	0.01	5.91***	−.03	0.01	−2.51	−.02	0.01	−1.64

Note: Significance coded as such $*p \leq .050$, $**p \leq .010$, $***p \leq .001$. All p-values after FDR correction.

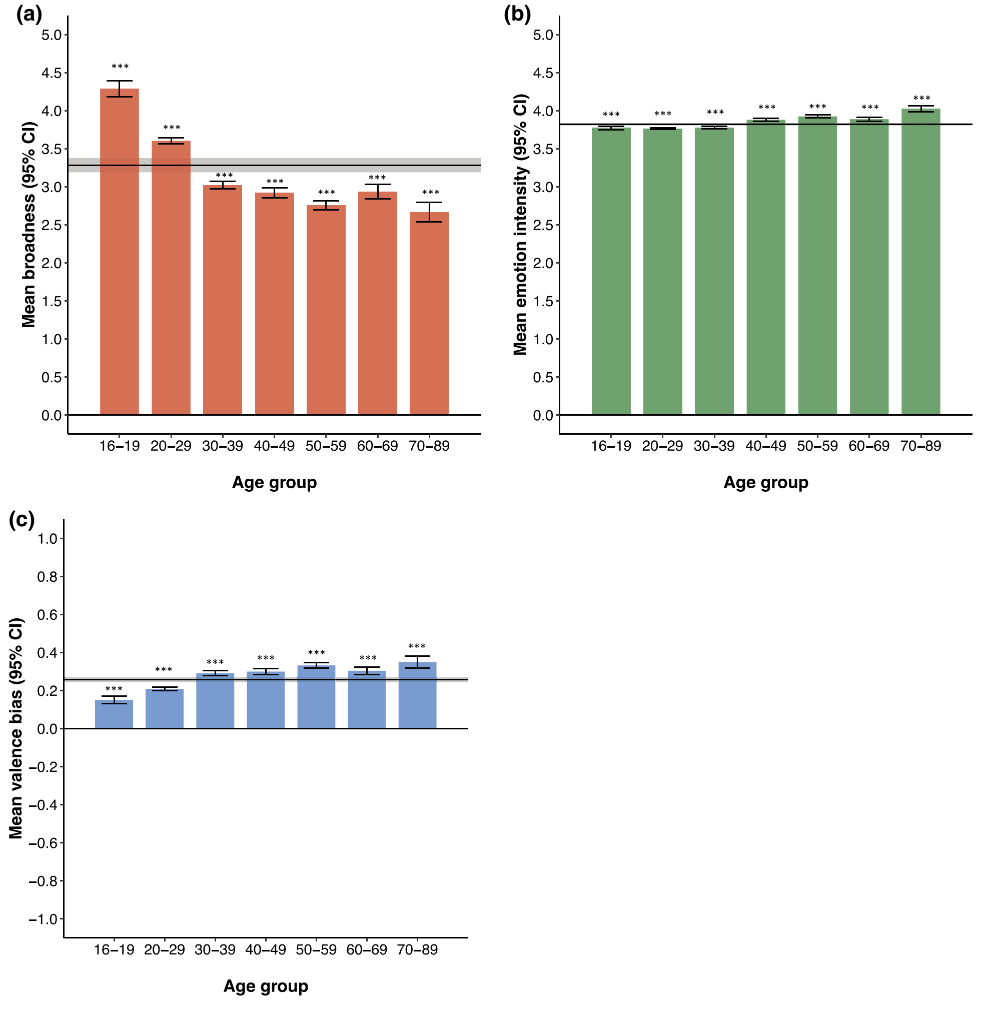

FIGURE 6 Age Group differences on broadness (a), emotion intensity (b) and valence bias (c). Horizontal line marks mean ratings across all participants while grey shadings mark 95% confidence intervals (CI). When 95% CI intervals overlap, the difference between two groups is not significant. Stars indicate cases when age group ratings were below or above these mean ratings (i.e., deviation contrast), after the correction for multiple comparisons (FDR); ***$p \le .050$.

remaining age groups (on average) while participants from all age groups above the age of 30 associated fewer emotions than average (Figure 6a). The main effect of colour, $F(11, 81{,}246) = 258.1$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .065, has been interpreted in the model on continuous age above. See Table S12 for the interpretation of the interaction between Colour and Age Group, $F(66, 81{,}246) = 6.24$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .071.

Age-related differences in the intensity of associated emotions

Across the colour terms, participants associated emotions with an average intensity of 3.82 (95% CI = [3.81, 3.83]). A linear mixed model with Age, Colour, Country and two-way interactions between Age and Colour, and Age and Country as predictors of emotion intensity was significant, $F(83, 13{,}302) = 80.01$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .082.

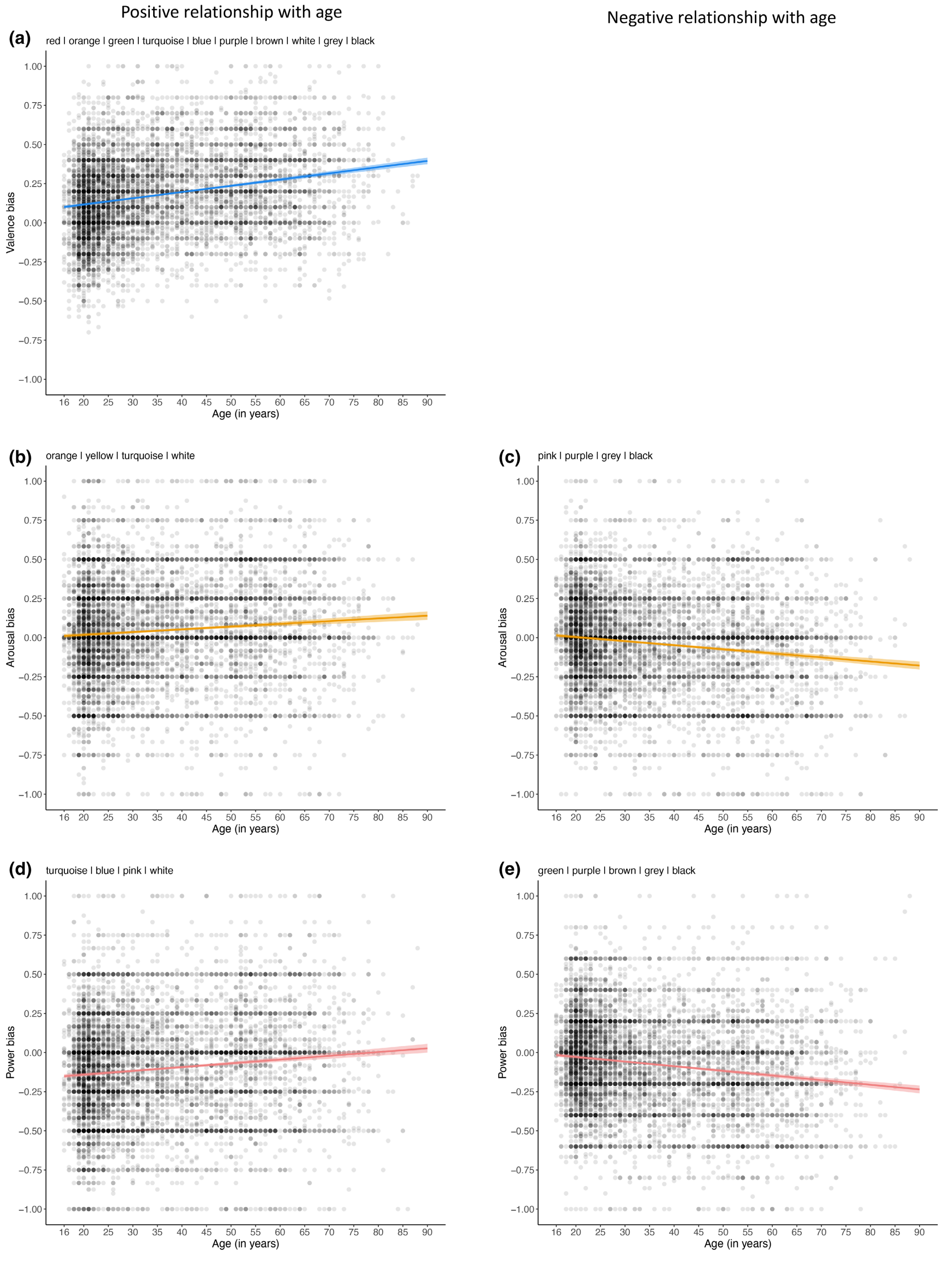

FIGURE 7 Affective biases predicted by Age. We only included colour terms showing significant main effects of age. Colours code for affective biases and are not related to the actual colour terms: blue – valence bias (a), orange – arousal bias (b, c), pink – power bias (d, e). Each point represents an individual participant, averaged across the relevant colour terms (listed above each figure). Also see Table 6.

The main effect of Age, $F(1, 7371) = 85.8$, $p < .001$, *pseudo-R*^{2} *(Nagelkerke)* = .001, suggested that with age, older participants associated emotions of higher intensity (Figure 5, Table 5). There were significant two-way interactions between (i) Age and Colour, $F(11, 75{,}127) = 13.4$, $p < .001$, *pseudo-R*^{2} *(Nagelkerke)* = .073 and (ii) Age and Country, $F(30, 7360) = 2.67$, $p < .001$, *pseudo-R*^{2} *(Nagelkerke)* = .001.

Older participants associated more intense emotions with all colour terms (see Table 6). Age was a significant predictor in 11 countries, in all of which the main effects of age had the same direction – with increasing age, participants gave higher emotion intensity ratings (Table 7).

Additionally, the main effect of Colour, $F(11, 75{,}116) = 92.1$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .071, highlighted that emotion intensity varied by colour term. *Red* was associated with the most intense emotions, whereas *brown* was associated with the least intense emotions (see Table S8). The main effect of Country, $F(30, 7360) = 4.29$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .007, highlighted that emotion intensity also varied by country. Participants coming from Saudi Arabia associated the most intense emotions, while those coming from Japan associated the least intense emotions (see Table S10).

An additional linear mixed model predicting emotion intensity from Age Group, Colour and a two-way interaction between Age Group and Colour was also significant, $F(83, 80{,}463) = 73.2$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .075. The main effect of Age Group, $F(6, 7439) = 12.2$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .001, indicated that emotion intensity differed across the age groups. Deviation planned contrasts showed that participants in the age groups below 40 years old associated significantly less intense emotions than did participants on average while participants from all the age groups above the age of 40 associated more intense emotions than average (Figure 6b). The main effect of Colour, $F(11, 75{,}072) = 299.1$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .071, has been interpreted in the linear model above. For the interpretation of the interaction between Colour and Age Group, $F(66, 75{,}072) = 3.83$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .075, see Table S13.

Affective biases

Age-related differences in valence bias

On average and across the colour terms, participants associated emotions biased towards the positive end of the valence dimension, $M = 0.256$, 95% CI = [0.251, 0.262], $t(88715) = 92.4$ $p < .001$, one-sample *t*-test. A linear mixed model with Age, Colour, Country and two-way interactions between Age and Colour, and Age and Country as predictors of valence bias was significant, $F(83, 13{,}264) = 596.8$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .389.

The main effect of Age, $F(1, 7336) = 187.2$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .005, suggested that as participants' age increased, participants associated emotions more strongly biased towards positive valence (Figure 7a; Table 5). This main effect was qualified by two significant two-way interactions: (i) Age and Colour, $F(11, 81{,}306) = 27.6$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .385 and (ii) Age and Country, $F(30, 7332) = 2.71$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .0011. For all colour terms, apart from *yellow* and *pink*, as age increased, participants associated emotions more strongly biased towards positive valence (see Table 6). Age was a significant predictor of valence bias in 19 out of 31 countries, in which the main effects of age went in the same direction – older participants associated emotions more strongly biased towards positive valence with all colour terms (see Table 7).

In addition, there was the main effect of Colour, $F(11, 81{,}306) = 738.8$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .379, highlighting that valence bias varied by colour term. Emotion associations with *pink* were most positively biased while associations with *black* were least positively biased (see Table S9). The main effect of country, $F(30, 7328) = 2.71$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .007, highlighted that valence bias varied by country. Participants coming from Nigeria produced the most positively biased emotion associations, while participants coming from Switzerland produced the least positively biased emotion associations (see Table S11).

The linear mixed model predicting valence bias from Age Group, Colour, and a two-way interaction between Age Group and Colour was also significant, $F(83, 86{,}661) = 591.8$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .386. The main effect of Age Group, $F(6, 7394) = 78.9$, $p < .001$, *pseudo-*R^2 *(Nagelkerke)* = .006, indicated that valence bias differed across the groups. Based on the deviation-planned contrasts, the valence bias was significantly lower in the age groups below 30 years old than on average, whereas the valence bias was significantly elevated in the age groups above 30 years old (Figure 6c). See Table S14 for the interpretation of the interaction between colour and age group, $F(66, 81{,}251) = 6.02$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .386, and see the linear model above for the interpretation of the main effect of colour, $F(11, 81{,}251) = 2525.5$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .379.

Age-related differences in arousal bias

Across the colour terms, participants on average associated emotions biased towards emotions of low arousal ($M = -.021$, 95% CI = [−.025, −.016], $t(88715) = -8.68$, $p < .001$, one-sample *t*-test). A linear mixed model with Age, Colour, Country and two-way interactions between Age and Colour and Age and Country as predictors of arousal bias was significant, $F(83, 13{,}238) = 274.2$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .231.

The main effect of Age was not significant, $F(1, 88{,}632) = 0.54$, $p = .464$, *pseudo*-R^2 *(Nagelkerke)* < .0001, meaning that arousal bias, when all colour terms and countries were considered together, did not differ with age (Table 5). However, there were two significant two-way interactions: (i) Age and Colour, $F(11, 88{,}632) = 19.2$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .0228 and (ii) Age and Country, $F(30, 88{,}632) = 2.20$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .003.

Age was a significant predictor for eight out of twelve colour terms but the effects went in two directions (Table 6). For one group of colour terms (i.e., *yellow*, *orange*, *turquoise* and *white*), as participants got older, they associated emotions biased more strongly towards high arousal (Figure 7b). For the second group of colour terms (i.e., *purple, pink, grey* and *black*), as participants got older, they associated emotions biased more strongly towards low arousal (Figure 7c). Age did not predict differences in arousal bias for *red*, *green*, *blue* and *brown*. Regarding country differences, age was only a significant predictor in Japan. As age increased, Japanese participants associated emotions of higher arousal with all colour terms (see Table 7).

In addition to the age-related effects, the main effect of Colour, $F(11, 88{,}632) = 319.5$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .226, highlighted that arousal bias varied by colour term. *Red* was associated with emotions which were the most strongly biased towards high arousal, whereas *brown* was associated with emotions which were the least strongly biased towards high arousal (see Table S9). The main effect of Country, $F(30, 88{,}632) = 3.02$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .002, highlighted that arousal bias also varied by country. Spanish participants associated emotions the most strongly biased towards high arousal while Austrian participants associated emotions which were the least strongly biased towards high arousal (see Table S11).

The linear mixed model predicting arousal bias from Age Group, Colour and a two-way interaction between Age Group and Colour was also significant, $F(83, 86{,}662) = 272.2$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .230. However, like above, the main effect of Age Group was not significant, $F(6, 7393) = 1.99$, $p = .064$, *pseudo*-R^2 *(Nagelkerke)* < .001. See Table S15 for the interpretation of the interaction between Colour and Age Group, $F(66, 81{,}251) = 4.89$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .230, and see the above linear model for the interpretation of the main effect of Colour, $F(11, 81{,}251) = 1168.5$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .226.

Age-related differences in power bias

Across the colour terms, participants associated emotions biased towards emotions of high power ($M = .011$, 95% CI = [0.007, 0.016], $t(88715) = 4.81$, $p < .001$, one-sample *t*-test). A linear mixed model with Age, Colour, Country and two-way interactions between Age and Colour and age and country as predictors of power bias was significant, $F(83, 13{,}238) = 132.4$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .125.

The main effect of Age was not significant, $F(1, 88{,}632) = 0.95$, $p = .330$, *pseudo*-R^2 *(Nagelkerke)* < .001, meaning that power bias, when all colour terms and countries were considered together, did not differ with age (Table 5). Nevertheless, there were two significant two-way interactions: (i) Age and Colour, $F(11, 88{,}632) = 28.6$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .123 and (ii) Age and Country, $F(30, 88{,}632) = 2.74$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .003.

Regarding Age interaction with Colour, the effects went in two directions (Table 6). As participants got older, they associated emotions biased more strongly towards high power with *blue*, *turquoise*, *pink* and *white* (Figure 7d). At the same time, as participants got older, they associated emotions biased more strongly towards low power with *green, purple, brown, grey* and *black* (Figure 7e). Age did not predict differences in power bias for *red*, *yellow* and *orange*. Regarding country effects, age was a significant predictor of power bias in two countries – Japan and Estonia, but the effects went in the opposite directions (see Table 7). Older Japanese participants associated emotions of higher power, whereas older Estonian participants associated emotions of lower power with all colour terms.

Finally, the main effect of Colour, $F(11, 88{,}632) = 171.5$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .119, highlighted that power biases varied by colour term. *Orange* was associated with emotions most strongly biased towards high power, whereas *grey* was associated with emotions least strongly biased towards high power (see Table S9). The main effect of Country, $F(30, 88{,}632) = 2.91$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .002, highlighted that power biases also varied by country. Serbian participants associated emotions the most strongly biased towards high power while Austrian participants associated emotions the least strongly biased towards high power (see Table S11).

The linear mixed model predicting power bias from Age Group, Colour and a two-way interaction between Age Group and Colour was also significant, $F(83, 86{,}662) = 131.3$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .124. Like above, however, the main effect of Age Group was not significant, $F(6, 88{,}632) = 1.91$, $p = .076$, *pseudo*-R^2 *(Nagelkerke)* < .001. See Table S16 for the interpretation of the interaction between colour and age group, $F(66, 88{,}632) = 6.82$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .124, and see the linear model above for the interpretation of the main effect of colour, $F(11, 88{,}632) = 539.0$, $p < .001$, *pseudo*-R^2 *(Nagelkerke)* = .119.

Summary of cross-cultural results

Based on Table 7, age was a significant predictor of broadness in 16 countries, emotion intensity – 11 countries, valence bias – 19 countries, arousal bias – 1 country and power bias – 2 countries. There were 5 countries in which age was a significant predictor of three variables (broadness, emotion intensity and valence bias) – Cyprus, Germany, Lithuania, Philippines and Sweden. However, these were not the countries with the highest sample sizes. Overall, the relationship between the sample size and the number of significant main effects of age was not significant, $F(1, 29) = 2.95$, $p = .096$, *partial* $R^2 = .061$.

DISCUSSION

The current study provides important baseline knowledge on age-related differences in colour–emotion associations and does so cross-culturally. We investigated such potential differences because there are various age-related physiological, psychological and affective changes (Barbur & Rodriguez-Carmona, 2015; Drag & Bieliauskas, 2010; Owsley, 2016; Reed & Carstensen, 2012) that might affect colour–emotion associations. With increasing age, individuals spend more time in a few (often indoor) spaces. Thus, colour choices might have stronger bearing on their overall functioning and well-being (Delcampo-Carda et al., 2019; Griber et al., 2020).

Across participants, we found 14 frequent colour–emotion associations, including *red*-love, *red*-anger, *yellow*-joy, *pink*-love, *pink*-pleasure, *orange*-amusement, *grey*-sadness, *black*-sadness, *black*-fear, some of which have been previously reported (Fugate & Franco, 2019; Hanada, 2018; Jonauskaite, Abu-Akel, et al., 2020; Jonauskaite, Parraga, et al., 2020; Kaya & Epps, 2004; Sutton & Altarriba, 2016). These associations were present irrespective of participants' age as colour–emotion association patterns were nearly identical across the age groups (Pearson *r* scores between .94 and .99, with an average of .97). That said, the youngest (16–19-year-old) and the oldest (70–89-year-old) participants produced the least similar colour–emotion association patterns, hinting at some age-related differences. In previous studies, colour–emotion association patterns were highly similar (i) cross-culturally among 30 nations (Jonauskaite, Abu-Akel, et al., 2020), (ii) when comparing emotion associations with colour terms and colour patches (Jonauskaite, Parraga, et al., 2020), and (iii) when comparing colour–emotion associations between those with and without red–green colour blindness (Jonauskaite et al., 2021). Thus, our current results reinforced the idea of stability and universality of colour–emotion associations in adulthood.

Study findings further indicated differences of small effect size across the age groups. First, older participants associated fewer but more intense emotions with all colour terms. These results indicated that (i) colour–emotion associations were more specific with age (fewer emotions associated with each colour) and that (ii) participants were more certain about their selections (higher emotion intensity rating), mirroring findings of a previous study (Jonauskaite, Abu-Akel, et al., 2020). Focusing on the opposite end of the age continuum, adolescents associated the largest number of emotions with colour terms, but these emotions were the least intense. Knowing that adolescents often have difficulties differentiating felt emotions (Nook et al., 2018), and that emotion abstraction continues developing (Nook et al., 2020), these results might reflect uncertainty in colour–emotion associations among adolescents.

Second, we confirmed an enhanced positivity effect in the elderly (Reed et al., 2014), because with age, participants associated more positive emotions with colour terms. Third, our age-related results did not selectively apply to colours falling on the yellow-blue axis, indicating that they were not driven by age-related changes in colour vision, such as lens brunescence (Barbur & Rodriguez-Carmona, 2015). The latter result was expected, since colour constancy ensures stable colour perception for changing environments as well as with advancing age, including changes in chromatic sensitivity (Hardy et al., 2005).

Finally, we found age-related differences in arousal and power (i.e., dominance) biases, but they depended on colour term. With age, *turquoise* and *white* were associated with more arousing and higher power emotions, whereas *black*, *grey*and *purple* were associated with less arousing and lower power emotions. Lightness might be the connecting factor for these findings (see focal colours in Lindsey & Brown, 2014), meaning that overall darker colours lose their arousal and potency as people get older. *Red* was the only colour term with no age-related differences in power and arousal biases. As *red* was associated with the most arousing emotions of all colour terms, our results signalled that the red-arousal association remained stable with age. The latter interpretation was also in line with a previous study (Ou et al., 2012), showing stable arousal judgements of red with age. However, we did not replicate lower arousal ratings of all colours in older participants (Ou et al., 2012).

Discrepancies between their and our results might come from cultural differences. Ou and colleagues (2012) studied Taiwanese participants, while this country was not part of the 31 countries investigated in the present study. Indeed, origin country might matter because not all age-related effects were significant in all countries. Nonetheless, the numerical effects, whether significant or not, went in the same direction in all 31 countries. Obviously, one explanation for the differences between countries could be statistical power, which increases with sample size (Faul et al., 2007). However, sample size did not predict the number of significant effects observed in a country, pointing towards alternative explanations such as genuine cultural differences.

Limitations and future directions

Here, we used colour terms as stimuli. We chose this methodology because currently, it is nearly impossible to ensure that colour presentation remains stable across different screens and environmental conditions (Colombo & Derrington, 2001). In previous studies, young adults associated similar emotions with colour terms and colour patches (Jonauskaite et al., 2021; Jonauskaite, Parraga, et al., 2020), supporting the idea that using colour terms is a valid approach. However, older individuals (on a group level) might have lower vividness of mental visual imagery (Gulyás et al., 2022), which might in turn affect imagery of colours when presented with colour terms. It is unclear whether vivid mental imagery of colours is necessary to associate colour terms with emotions (perhaps not, as even colour-blind individuals produce similar associations; Jonauskaite et al., 2021). Older adults might also have smaller colour vocabularies (Griber et al., 2021). As we studied basic colour terms, presumably known to all speakers of a language (Berlin & Kay, 1969; Kay et al., 2009), this concern might be more applicable to the non-basic colour term (i.e., *turquoise*). Yet, we observed no age-related differences in colour–emotion associations, which were specific to *turquoise*.

Overall, we had a limited amount of information on our participants because we kept the online survey relatively short. This also meant that we were unable to run vision tests and had to rely on self-report, for instance, by excluding participants who indicated having trouble seeing colours (i.e., who were presumably colour blind). Thus, to test for the stability of our results, whether using colour terms or colour patches, future studies should be run in the laboratory, testing not only participants' colour vision (Conway et al., 2018) but also other basic visual functions, such as visual acuity and contrast sensitivity (Owsley, 2016). Indeed, a within-subject study showed that basic visual functions rarely correlate with each other (Cappe et al., 2014). Then, future studies should also test both older participants experiencing healthy ageing and those with abnormal changes in colour vision (e.g., those with cataracts or macular degeneration; Barbur & Rodriguez-Carmona, 2015). In future studies, participants' living environments is also worth considering, as some individuals might have spent more time in urban versus rural regions, others more time indoors versus outdoors, and yet others in green versus arid environments. Indeed, green spaces can positively impact well-being (Briki & Majed, 2019; Li et al., 2023; Ma et al., 2019; Nakshian, 1964). As older participants have already a stronger liking for green colours than younger participants (Dittmar, 2001; Nemcsics & Takács, 2019a), green might become even more pleasant (and important) with age.

Some of the observed age-related differences in colour–emotion associations might have emerged due to an extreme response bias in the elderly (Van Vaerenbergh & Thomas, 2013). This bias would predict that with age, individuals preferentially select the extreme endpoints on rating scales. Applied to our study, such an extreme response bias might explain why our older participants associated more intense emotions with colour terms because the most intense emotions were selected when clicking on the biggest circles at the outer edge of the GEW. While possible, the literature on the relationship between extreme response style and age is mixed. Some studies, including a meta-analysis, reported that older participants have a less pronounced extreme response bias (Batchelor & Miao, 2016), while others reported the opposite (Meisenberg & Williams, 2008; Schneider, 2018). Also, a recent large-sample study with 173,000 participants found that cognitive abilities were more important than age to account for extreme response bias (Klar et al., 2022). Extreme response bias also differed as a function of participants' gender, culture, education and personalities (Batchelor & Miao, 2016; Harzing, 2006; Klar et al., 2022; Meisenberg & Williams, 2008). Therefore, only future studies can disentangle whether and how extreme response bias might impact colour–emotion associations.

Finally, the current study used a cross-sectional study design, with which we cannot separate the potential influence by cohort and age. We know that individuals of different cohorts have lived through vastly different historical times. They experienced different challenges, also of emotional nature (e.g., wars, human-caused and natural disasters, economic turmoil, etc.) and these experiences further depended on one's country of residence and socioeconomic status. Cross-sectional studies cannot account for such generational and context-specific effects. Perhaps, our results would look different if we had collected colour–emotion associations with a longitudinal design, over an extended period of time. No such study exists on colour–emotion associations to our knowledge, apart from one longitudinal study, showing seasonal influences on colour preferences, testing participants nine times over 11 weeks in autumn (Schloss & Heck, 2017).

Practical implications

Returning to the beginning of this article, we were concerned with colour selections that would benefit people with reduced mobility, focussing on older age. In the current study, we showed that findings from younger populations can be largely applied to older populations. With this knowledge at hand, one might be tempted to use these results in applied settings such as interior design, health sector or marketing, for instance, by designing interior spaces using colours having positive connotations. However, colour–emotion associations studied here and in most other previous studies were abstract and had little to do with actual feelings. It remains to be seen whether and in which circumstances such widely shared colour–emotion associations directly impact human emotions and psychological functioning. It is problematic to simply assume that looking at colours associated with positive emotions would also induce a positive affective experience and vice versa (see Kaiser, 1984; Weijs et al., 2023; Wilms & Oberfeld, 2018). Applied experimental studies are needed to provide empirical evidence that allows translation into practice.

When choosing colours for interior and exterior spaces, professionals must decide whether they should follow results on colour–emotion associations or colour preferences. Preferences are defined as relatively stable evaluative aesthetic judgements in the sense of liking or disliking a colour, generating unspecific positive or negative feelings (Scherer, 2005). Thus, by definition, they are less specific than colour–emotion associations, and, on some occasions, colour–emotion associations might differ from preferences (e.g., pink is a positive yet often disliked colour; Jonauskaite, Dael, et al., 2019). Previous studies showed both similarities and differences in older participants' colour preferences (Beke et al., 2008; Dittmar, 2001; Jung et al., 2022; Nemcsics & Takács, 2019a, 2019b; Ou et al., 2012; Silver & Ferrante, 1995; Torres et al., 2020; Zhang et al., 2019). For example, older Asian participants preferred warmer, darker, and more muted colours than younger participants (Zhang et al., 2019). Yet, overall, they liked all colours to a lower extent than younger participants (Ou et al., 2012; Zhang et al., 2019), resembling our current findings that older participants associated fewer emotions with colours. These observations might make colour selections for elderly more challenging.

CONCLUSIONS

This is the first large-scale intercultural study systematically investigating age differences in colour–emotion associations. Our 7393 participants between 16 and 88 years old came from 31 nations. They associated similar colours with emotions, vouching for comparability across adulthood. We also found small but meaningful age differences. First, older participants associated fewer but more intense and more positive emotions with all colour terms, supporting a general positivity effect in cognitive functions (Reed et al., 2014). Second, patterns of colour–emotion associations were most different in late adolescents and the oldest adults (i.e., over 70 years old), suggesting that colour–emotion associations become most stable in middle adulthood (i.e., between 30 and 49 years old). Third, age-related differences in arousal and power ratings depended on the colour in question. We did not find that any finding to be more pronounced for colours along the yellow-blue axis, indicating that age-related changes in colour perception are of low relevance and likely compensated by colour constancy mechanisms (Barbur & Rodriguez-Carmona, 2015; Hardy et al., 2005). Future studies are needed to bridge the gap between abstract colour–emotion associations and felt emotions, important when making colour choices for applied purposes, such as hospitals or elderly homes. For that, one must assess felt emotions, which can be challenging to achieve (Kaiser, 1984; Weijs et al., 2023).

AUTHOR CONTRIBUTIONS

Domicele Jonauskaite: Conceptualization; investigation; funding acquisition; writing – original draft; methodology; validation; visualization; writing – review and editing; software; formal analysis; project administration; data curation; supervision; resources. **Déborah Epicoco:** Investigation; methodology; validation; writing – review and editing; data curation; resources; software. **Abdulrahman S. Al-rasheed:** Investigation; resources; writing – review and editing. **John Jamir Benzon R. Aruta:** Resources; investigation; writing – review and editing. **Victoria Bogushevskaya:** Investigation; writing – review and editing; resources. **Sanne G. Brederoo:** Investigation; writing – review and

editing; resources. **Violeta Corona:** Investigation; writing – review and editing; resources. **Sergejs Fomins:** Investigation; writing – review and editing; resources. **Alena Gizdic:** Investigation; writing – review and editing; resources. **Yulia A. Griber:** Investigation; writing – review and editing; resources. **Jelena Havelka:** Investigation; writing – review and editing; resources. **Marco Hirnstein:** Investigation; writing – review and editing; resources. **George John:** Investigation; writing – review and editing; resources. **Daniela S. Jopp:** Conceptualization; funding acquisition; writing – review and editing; supervision. **Bodil Karlsson:** Investigation; writing – review and editing; resources. **Nikos Konstantinou:** Investigation; writing – review and editing; resources. **Éric Laurent:** Investigation; writing – review and editing; resources. **Lynn Marquardt:** Investigation; writing – review and editing; resources. **Philip C. Mefoh:** Investigation; writing – review and editing; resources. **Daniel Oberfeld:** Investigation; writing – review and editing; resources. **Marietta Papadatou-Pastou:** Investigation; writing – review and editing; resources. **Corinna M. Perchtold-Stefan:** Investigation; writing – review and editing; resources. **Giulia F. M. Spagnulo:** Writing – review and editing; software; data curation. **Aygun Sultanova:** Investigation; writing – review and editing; resources. **Takumi Tanaka:** Investigation; writing – review and editing; resources. **Ma. Criselda Tengco-Pacquing:** Investigation; writing – review and editing; resources. **Mari Uusküla:** Investigation; writing – review and editing; resources. **Grażyna Wąsowicz:** Investigation; writing – review and editing; resources. **Christine Mohr:** Conceptualization; investigation; funding acquisition; writing – original draft; methodology; validation; writing – review and editing; project administration; supervision; resources.

AFFILIATIONS

[1]Institute of Psychology, University of Lausanne, Lausanne, Switzerland
[2]Faculty of Psychology, University of Vienna, Vienna, Austria
[3]Department of Psychology, King Saud University, Riyadh, Saudi Arabia
[4]Department of Psychology, De La Salle University, Manila, Philippines
[5]Department of Humanities, University of Salento, Lecce, Italy
[6]University Center for Psychiatry, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[7]School of Economics and Business Administration, Universidad Panamericana, Mexico City, Mexico
[8]Business Management Department, Universitat Politècnica de València, Valencia, Spain
[9]Department of Optometry and Vision Science, Faculty of Physics, Mathematics and Optometry, University of Latvia, Riga, Latvia
[10]Department of Clinical and Health Psychology, Universitat Autònoma de Barcelona, Barcelona, Spain
[11]Department of Sociology and Philosophy, Smolensk State University, Smolensk, Russia
[12]School of Psychology, University of Leeds, Leeds, UK
[13]Department of Biological and Medical Psychology, University of Bergen, Bergen, Norway
[14]Department of Biotechnology, Government of India (formerly), New Delhi, India
[15]Institute of Psychology and LIVES Center of Competence, University of Lausanne, Lausanne, Switzerland
[16]Division Built Environment, RISE Research Institutes of Sweden, Gothenburg, Sweden
[17]Department of Rehabilitation Sciences, School of Health Sciences, Cyprus University of Technology, Limassol, Cyprus
[18]Laboratoire de recherches Intégratives en Neurosciences et psychologie Cognitive (LINC), Université de Franche-Comté, Besançon, France
[19]Section for Clinical Neurophysiology, Department of Neurology, Haukeland University Hospital, Bergen, Norway
[20]Department of Psychology, Faculty of the Social Sciences, University of Nigeria, Nsukka, Nigeria
[21]Institute of Psychology, Johannes Gutenberg University Mainz, Mainz, Germany
[22]Department of Primary Education, National and Kapodistrian University of Athens, Athens, Greece
[23]Department of Psychology, University of Graz, Graz, Austria
[24]National Mental Health Centre, Baku, Azerbaijan
[25]Graduate School of Humanities and Sociology and Faculty of Letters, The University of Tokyo, Tokyo, Japan
[26]Department of Psychology, College of Science, University of Santo Tomas, Manila, Philippines
[27]School of Humanities, Tallinn University, Tallinn, Estonia
[28]Department of Economic Psychology, Kozminski University, Warsaw, Poland

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CONFLICT OF INTEREST STATEMENT

We have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in OSF at https://osf.io/873df/.

ORCID

Domicele Jonauskaite https://orcid.org/0000-0002-7513-9766

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