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THE COLOURS OF EMOTIONS

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Abstract

Colours and emotions are everywhere. From natural language to advertisement the connection between the two tries to evoke a certain emotion. This study wanted to explore whether there was evidence for making this connection by investigating the hypothesis: Emotions are coloured. This was done by having 18 people (12 females, mean age= 23.6, sd=3.8) create the colour they deemed matched the emotion displayed on facial expressions from a matrix of four different faces (two males). One colour was made for each of 6 different emotions using HSV colour space. Participants then completed 3 forced choice tasks consisting of two preference tasks and one congruency task. The following was found: 1) A significant difference between the frequency of congruently and incongruently chosen colour. 2) A significant difference between the frequency of congruently and neutrally chosen colour. 3) In both cases the frequency of congruently chosen colours was greater. Furthermore, specifically made colours for emotions were sufficient in predicting participants personal generated colours, indicating a distinctiveness in colours generated to match emotions. No significant difference was found between the frequency of incongruently and neutrally chosen colours. However, it is suspected there were flaws in the design of the neutral-incongruent condition. Based on the findings of this study, there seems to be evidence for a non-arbitrary connection between colours and emotions. Due to low statistical power and other shortcomings, a replication of the study with a larger sample size as well as modifications to the experimental design is needed to further support the hypothesis of emotions being coloured.

Keywords: emotional facial expressions, colours, forced-choice task, emotion-colour associations

Maria Mujemula Olsen (herein after MO) and Sara Kjær Kristensen (herein after SK) have both contributed to and worked on every part of the paper. For individual assessment each section has been marked with a responsible writer's initials. If an initial mark is missing, the paragraphs responsibility belongs to the previous paragraph's writer.

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1 Introduction

1.1 Motivation (SK)

The seeing world is colourful for most people. Navigating society is often aided by red and orange traffic signs to signal danger or distress; and rosa waiting rooms for calming the nerves. All use colours and emotions, making the association apparently ubiquitous (Madden et al., 2000; Ou et al., 2018; Wilms & Oberfeld, 2018).

Emotions and colours are linked in cultures by symbols and signs, especially in language. In English one can be 'green with envy' or 'have the blues'. In Danish one can too be 'green and yellow with envy' ('være gul og grøn af misundelse') or can 'get red buds' ('få røde knopper'), an idiom for getting annoyed. The Chinese idiom '面红耳赤 ' [miàn hóng ěr chì] (in English: red face red ears) means getting embarrassed. The context may vary according to the environment, shape, or the individual differences e.g., age (Terwogt & Hoeksma, 1995) and mother tongue (Casaponsa & Athanasopoulos, 2018). In this paper we dive into facially expressed emotions and personally adjusted colours, to explore the link between emotions and colours.

1.2 Colours

1.2.1 Natural colours (SK)

Colours are widely used in nature, as it is the prime example of guiding attention. Bees can differentiate flowers depending on colours and patterns (Hempel de Ibarra et al., 2022) and birds use their plumage to attract mates. In one of the earliest works on colours, colours were described as naturally made from the four elements of nature (*De Coloribus*, 1936). The theory of colours took an interesting turn with Newton and a prism. He described the visible part of the electromagnetic spectrum with the terms; hue, chroma and lighting. The system's brother is known as hue, saturation and value (HSV) (see fig. 1). Hue is a part of the Newtonian colour circle which covers the red, green and blue (RGB) primary colours including the mixes of colours. Whereas saturation and value determine the nuance of the colour in two ways. Saturation is the amount of grey the colour has on a scale from grey to the neon version of the colour. The value determines the brightness of the colour on a scale from black to the neon version in conjunction with saturation (Howard Bear, 2020).

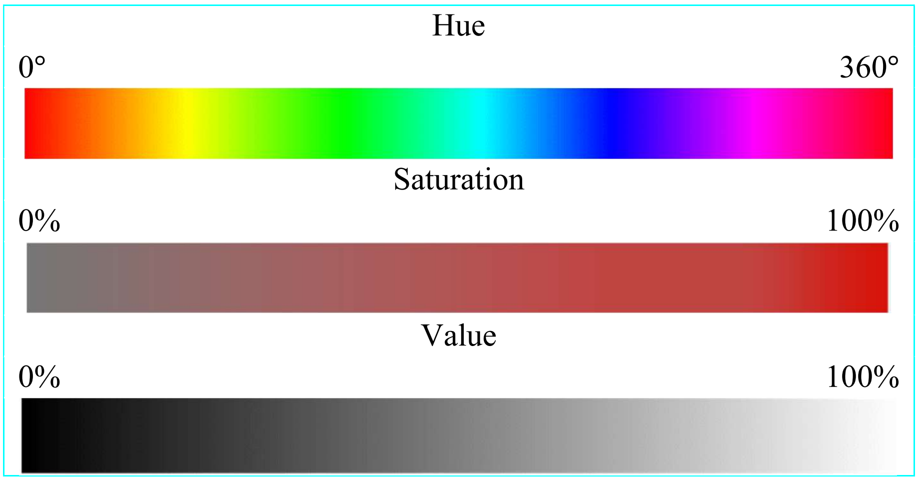

Figure 1 - Hue, saturation and value spectrums based on figures from (Understanding Hue, Saturation & Lightness (HSL) for Photo Retouching, 2016) and Simmon (2013).

1.2.2 Colour perception (MO)

As with many processes between the physical world and the subjective experience, the human body receives a signal whereafter this signal is processed and interpreted (APA, n.d.). Therefor we do not perceive the colours one-to-one with "reality". The signal being interpreted is electromagnetic waves. The electromagnetic waves vary in length, and it is only a small part of the electromagnetic spectrum that is visible for the human eye (Rye et al., 2016). The visible part of the electromagnetic spectrum is often referred to as coloured, as it is these wavelengths that gets perceived as colour. The construction of the eye is now put under the microscope as it is key to understanding how colour is perceived.

When light hits the outer spherical lens, the cornea, the waves converge into a focal point which is projected towards the retina (Sánchez López de Nava et al., 2022). The retina is equipped with cones and rods. The rods are responsible for detecting brightness and are used to see in the dark. The cones are what we use for perceiving colour. There are 3 types of cones: red (L), blue (S) and green (M) (Rye et al., 2016). The cones will activate at certain wavelengths, and each cone is sensitive to different areas of wavelengths, which can be seen in figure 2. When one or more cones do not respond to their array of wavelength, it is called colour-blindness (Turbert, 2022).

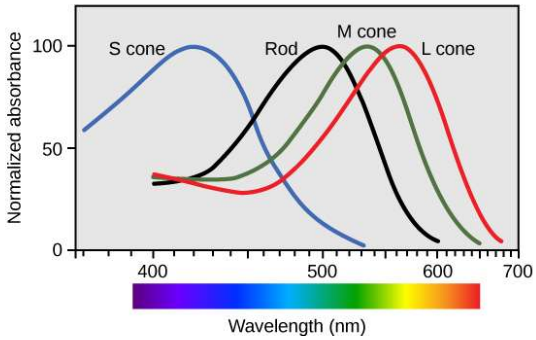

Figure 2 - Excerpt from the electromagnetic spectrum with visible light. Colour and cone/rod distribution in ascending wavelength order. The figure is from Rye et al. (2016).

When a cone is activated, it will send a signal which travels through the optic nerve before it is processed in the visual cortex of the brain. The combination of cone-activation is important for which colours is being perceives (Rye et al., 2016). For example, if mainly L cones are activated the colour red will be perceived. Whereas the perceived colour white is in terms of physics all wavelengths hitting the retina activating the corresponding wide distribution of cones. The perception of the colour white could also be the result of S, R and L cones being activated by an equal intensity of red, blue and green wavelengths. In that sense, our perception of colour is not a direct reflection of reality but an interpretation.

The interpretation continues as people navigate their environments linking colours with different attributes. For example, when taking a photo photographers use saturation actively to connote different emotions, making desaturated photos to constrained emotions and vice versa (*Hue*, *Saturation*, *Value*, 2021). This premise is supported by research showing that active (e.g. joyful) versus passive (e.g. sadness) emotion have higher versus desaturated chromatic colours respectively (Ou et al., 2004a, 2004b). With the possible link between colours and emotions we now dive into the field of emotions.

1.3 Emotions (SK)

Emotions are complex mental states (Oosterwijk et al., 2012). If moods are the long stretching and slowly forward moving polynomials of mental states, then emotions are the small fluctuations. An excerpt of the dimensions of emotions are its hedonic value and feeling state (Ward, 2020). Where the hedonic value covers the subjective evaluation of what one is feeling, much like how an emotional stimulus draws attention to prompt a response. The feeling state is the physiological response, for example when the student's heartrate increases during the oral exam due to nervousness or the measure skin conductance and sweat during decision making (see (Dawsen et al., 2011) for elaboration).

Since emotions are multidimensional there are many ways to be happy like being joyful, appreciative or feeling the joy of reunion. Paul Ekman made a famous argument for covering the emotion span of man with six basic emotion (Ekman, 1992, 2000). The six categories comprise of anger, disgust, fear, happiness, sadness and surprise. These categories are interculturally recognizable. Being able to communicate and mentalizing the mental states of the people around is a huge player in social interaction. For that reason, a manual for 6 appropriate facial expressions have been created to reflect the six basic emotions (Ekman & Friesen, 1978). An actor may master the scientific and professional way of expressing emotions, but for everyday expression emotion is a valuable tool when connecting to the outside world.

Emotions are often used in unconscious ways, for instance as in facial expressions or body language. Even facial expressions and body language can be somewhat controlled consciously, but the subtle signs and being able to read the mental state of the person standing in front of you is quite the task. There is a lot of intervening variables can both help and/or lead astray when trying to read somebody's mental state. Sometimes one's emotional intelligence (Salovey & Mayer, 1990) does not suffice, for example with the case of utterances contradicting body language. Other times simple physical measures, like the pale- and redness in a person's face, aid this understanding, (da Pos & Green-Armytage, 2007). Depending on the blood flow in a person's face the skin can change colour. The most unconfutable example is when a relatively pale skinned person gets embarrassed or angry, which is expressed in the cheeks blush, as in the Chinese idiom mentioned earlier. Another example is a relatively brown skinned person becoming tired or nervous, expressed in the face turning pale in colour tone. We will now dive into findings from studies aiming at linking emotions and colours.

1.4 Linking colours and emotions (SK)

Cross modal correspondences have a long history of systematically associating the apparent unlinked sensory features and modalities (Spence & Parise, 2012). As many other have tried to link emotions and colours (e.g. Lin et al. (2021)) to other modalities and features (haptic see Obrist et al. (2015) or Ludwig & Simner (2013)), so have da Pos and Green-Armytage (2007). In their experiment they overlap emotional facial expressions with colours. Their findings of comparing Australian and European colour choices include correlations between arousal and colours, with higher saturation characterizing active emotions and increasing observer's arousal independently of their hue. Additionally, the value (lightness) of colours related to the emotions; fear, happiness and surprise had light colours, anger had dark colours, whereas sadness and disgust were associated with intermediate lightness.

Lastly, saturation for sadness and fear was desaturated and highly saturated for happiness, surprise and anger. Passive versus active emotions linking to their saturation, as colourful. Even when comparing across age groups too, which development approach studies also support (Terwogt & Hoeksma, 1995). With their design and psychology approach they find several colour and emotion combination go beyond boarders.

2 Experimental choices
(SK)

In this paper we want to explore this link between emotions and colours by posing a general hypothesis: Emotions are coloured. We will now go into depth with our approach and choices for the experimental setup.

2.1 Faces (SK)

In order to investigate emotions, we use facial expressions from the FACES database (Ebner et al., 2010). Since surprise and fear are frequently confounded, the FACES database has chosen to exclude facial expressions of surprise (Ebner, Luedicke, et al., 2018) and replaced it with a neutral facial expression. The database therefore includes both non-expressive (neutral) and expressive emotions (anger, disgust, fear, happiness and sadness). See figure 3 for example images.

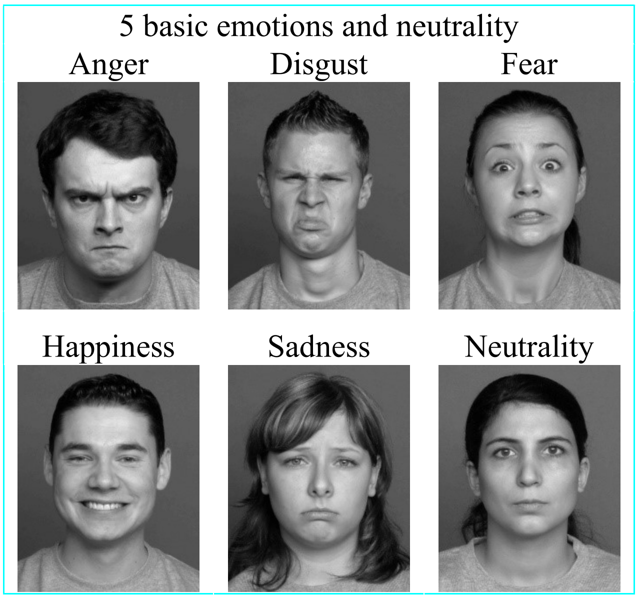

Figure 3 - Example images from the FACES collection (Ebner et al., 2010) displaying different emotional facial expressions.

As attractiveness can be represented in facial features with highly social relevance, we account for this by only including young faces and perceivers to limit noise in the stimuli and participants' differences (Orgeta & Phillips, 2007). Because A) young perceivers give biased ratings in preference ratings of attractiveness young versus middle aged and older faces (Ebner, Luedicke, et al., 2018). B) Young perceivers are better at recognizing the different emotions in the faces from the database (Ebner et al., 2010). C) Expression identification is easier in young and middle-aged faces than in the older category (Ebner, Luedicke, et al., 2018). This is all in line with the similarity hypothesis stating people are more attractive to individuals with similar attributes as themselves (Sappenfield & Balogh, 1970). All images were grey scaled in order to minimize uncontrollable biological factors, such as blood flow, interfering with emotional recognition. Furthermore, in order to avoid facial recognition interfering with the results, participants will only be shown a specific face once throughout the experiment.

2.2 Colour choice (SK)

As personal experience shapes the interpretation of the world (Series & Seitz, 2013), we therefore expect people to like and choose different colours for different emotions. In addition to this point, emotions are multifaceted and so would we expect the colour to be. Although the spectrum of emotions has been put to a graspable scale, colours have their own way of contrasting each other. Because of the emotion category a colour falls under differs dependent on nuances and different degrees of intensity, we have chosen to include a task for participants to generate a colour they "feel fit" to each of the six emotion categories.

2.3 Choice consistency (MO)

If emotions are coloured, we expect there to be consistency between which colours get associated with different emotions. Especially in cases where there is no assumed right choice. Consequently, participants will be asked to complete a colour-emotion matching task, which will be described further in section 4.3. It is expected that given the choice between two personally designed colours; participants will choose the colour consistent with the emotion it was originally designed after. Hereon after this will be referred to as a congruent choice. When given the choice between a neutral and an 'incongruent' colour, it is expected participants will choose the neutral colour. As we expect the participants would rather choose a neutral colour than choose a colour, they 'feel matches' another emotion.

2.4 Preference (MO)

Even though participants will not be asked to make their favourite colour, they still may generally prefer one colour over another. Same goes for emotions. Additionally, people are expected to have different approaches to what emotion and colour they prefer over the others. To get an insight into whether colour-emotion associations are influenced by preferences of colours and emotions, preference tasks are included in the experiment described in section 4.3. Here participants are not asked to choose their favourite colour/emotion, but rather which colour/emotion they preferer over another. If participant's preferences influence their colour-emotion association, it is expected they will consistently associate preferred colours with preferred emotions. This would indicate an underlying effect in colour-emotion associations. Using a simple relative count method, we can set up preference scales with most selected colours or emotions as "most preferred" and least selected as "least preferred". This will allow us to compare colour choices in colour-emotion matching conditions with the preference scales.

3 Hypotheses (MO)

As the aim of this study is to investigate whether emotions are colours, we pose the following hypotheses:

H1: The personally generated colours are distinctive depending on their hue, saturation and value, which can be predicted by their assigned emotion.

H2: When given the choice of matching a congruent or incongruent colour to a displayed emotion, the frequency of congruently chosen colours is significantly greater.

H3: When given the choice of matching a congruent or a neutral colour to a displayed emotion, the frequency of congruently chosen colours is significantly greater.

H4: When given the choice of matching an incongruent or a neutral colour to a displayed emotion, the frequency of the neutrally chosen colours is significantly greater.

4 Experimental setup (SK)

4.1 Participants

18 non-colourblind students from Aarhus University (12 females) in ages from 20 to 37 (mean = 23.6, sd = 3.8) participated. The participants were informed about the studies objective and gave their consent prior to the experiments start.

4.2 Stimuli

The FACES collection (Ebner, Riediger, et al., 2018) of grey scaled static faces from collection A was subdivided as previously discussed (n=358). The faces used had an age range from 19-31 (mean

= 24.4, sd = 3.4) with an equal gender distribution (Ebner et al., 2010). A face was only shown once, and the order was randomized.

4.3 Experimental workflow

All data collection and experimental procedure was completed in one coherent experiment coded using partly Psychopy (Peirce et al., 2019) builder (v2021.2.3) and coder (v2022.2.4) interface. After completing demographics, the participants were to complete four tasks: one colour generating task and three forced-choice tasks. All choice frames were visible until a response was made. The experiment was conducted using a laptop with 1920x1080 pixels and a framerate of 60 Hz. Prior to the forced choice trials a visual mask of binary black and white squares was shown for a duration of 3 frames (~50 ms), followed by a fixation crosses shown for 30 frames (~500 ms), see figure 4. The experiment took about 15 minutes to complete. All participation was voluntary, and the participants could exit at any point. No compensation was given. The four tasks will now be described in detail.

1. Colour generating task: The first task the participants were told to "make the colour you feel fit the best to the emotion". This colour will be referred to as the 'Participant dependent Emotional Colour' (PEC). The screen displayed a hue and saturation colour space with a value bar on the bottom and three sliders to navigate the colour spaces. See figure 4 for example. In the middle, a polygon with the final colour was shown as feedback. Four faces displaying the same emotional facial expression was shown during the entire task. Each participant completed the task once for each emotion category (= 6 trials).

2a. For the next two tasks we did a paired comparison test for the emotional facial expression on their PEC. Emotional-preference task: Participants were told to "choose as quickly as possible the picture" they "like[d] the best", as two faces displaying different facial expressions approximately 8x8 cm with 12 cm apart. Each unique emotion combination was displayed 4 times controlling for left and right positioning (= 60 trials).

2b. Colour-preference task: Using the PECs in same dimensions as in 2a, each unique combination was displayed 4 times (= 60 trials).

3. Colour-emotion matching tasks: In this set of trials participants had to match a PEC to a facial expression. Participants were told to as "quickly as possible chose the colour you feel fit the best to the displayed picture", with the colours in the corners, approximately 20 cm apart, and

face in the middle, see figure 4. All three elements were 6x6. The PECs displayed on the screen were either congruent, or incongruent with the facial expression displayed. This task had three different choice-possibilities: congruent/incongruent, neutral PEC/congruent and neutral PEC/incongruent. All participants went through 50 congruent/incongruent trials. 10 participants went through 10 neutral PEC/congruent trials and 8 participants went through 10 neutral PEC/incongruent trials. In the congruent/incongruent trials faces expressing a neutral emotion as well as the neutral PEC was filtered out, leaving 5 colours and emotion categories. In the neutral trials, only the neutral facial expressions were filtered out, leaving 5 emotion categories and 6 PEC. The order of neutral and consistency trials was randomized.

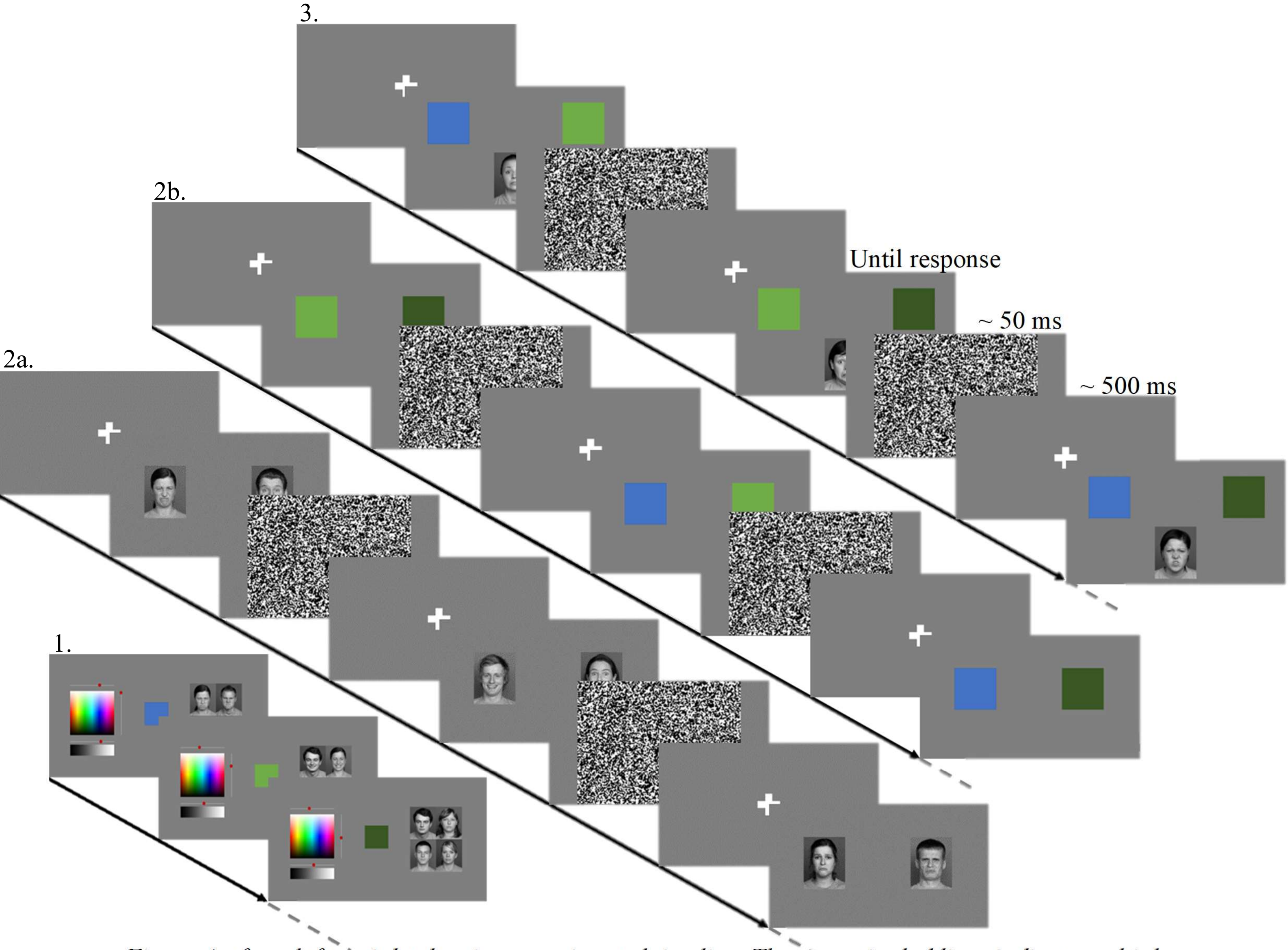

Figure 4 - from left to right showing experimental timeline. The grey stippled lines indicate multiple trials and each black arrow indicate a different task. Frame duration is noted on the corner for fixation, mask and choice frames.

5 Analysis

(SK)

Throughout the analysis we use an alpha level of 0.05 to discriminate p-values' significance. A p-value above the alpha level will be interpreted as supporting the null hypothesis with no significant difference in the compared means. The dataset was checked and accounted for outliers. Colours displayed in plots are calculated from the PECs into RGB colour space and then translated into html hexacodes.

5.1 PECs (SK)

5.1.1 PECS and prediction by emotion

In order to assess H1 on diverse PECS we inspected the hue, saturation and value variables. Generally, participants choices span widely on the intervals for the three colour variables: hue ranging from 0 - 358 (mean = 146.38, sd = 119.48), saturation ranging from 0 - 1 (mean = 0.61, sd = 0.23), and value ranging from 0.05 - 1 (mean = 0.65, sd = 0.61). Secondly, we did a visual inspection of the general picture of the PECs:

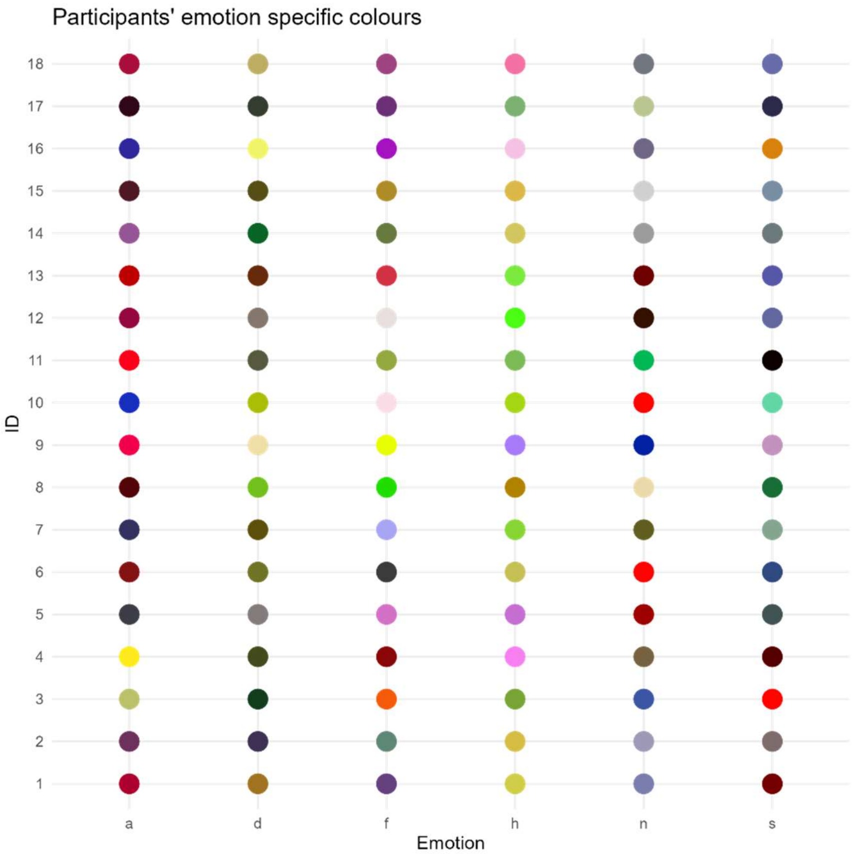

Figure 5 - Colours made for specific emotions in participant distribution, with participant ID on the y-axis and associated emotion on the x-axis displayed in alphabetic order.

We made cut offs for the colour variables (see 10.1) in order to quantify what kind of general colours were chosen to the different emotions:

Emotion\Colour	Black	Red	Purple	Blue	Green	Yellow	Orange
Anger		12		4	1	1	
Disgust		1	1		9	5	2
Fear		5	3	2	5	1	2
Happy		3	2		7	6	
Neutral		6		6	2	3	1
Sad	1	5		8	3	1	
Total	1	32	6	20	27	17	5

Table 1 - The distribution of colour categorises of different emotion categories.

By visually glancing at figure 5 and table 1, we see there are some systematicity per emotion and no individual who made the same colour for all emotions.

Thirdly, we investigate if the emotion displayed to the participant whilst making the colour influences the choice of colour. We do with generalized linear models with a gamma log distribution using the stats package included in R version 4.2.2 (R Core Team, 2022) :

$$Hue \sim Emotion,$$

We do this repeatedly for hue, saturation and value by releveling the baseline emotion in order to compare between which PECs there would be a difference.

Colour variable p-value below 0.05 & p-value above 0.05

Colour variable						
Hue	Anger					
	Disgust					
	Fear					
	Happy					
	Neutral					
	Emotion	Sad	Neutral	Happy	Fear	Disgust
Saturation	Anger					
	Disgust					
	Fear					
	Happy					
	Neutral					
	Emotion	Sad	Neutral	Happy	Fear	Disgust
Value	Anger					
	Disgust					
	Fear					
	Happy					
	Neutral					
	Emotion	Sad	Neutral	Happy	Fear	Disgust

Table 2 - showing between what emotion categories there is a significant difference in colour variable choice. Areas left blank have the same value as the opposite, e.g., disgust/fear is both insignificant as disgust/fear and fear/disgust for hue.

PEC's categorised by emotion

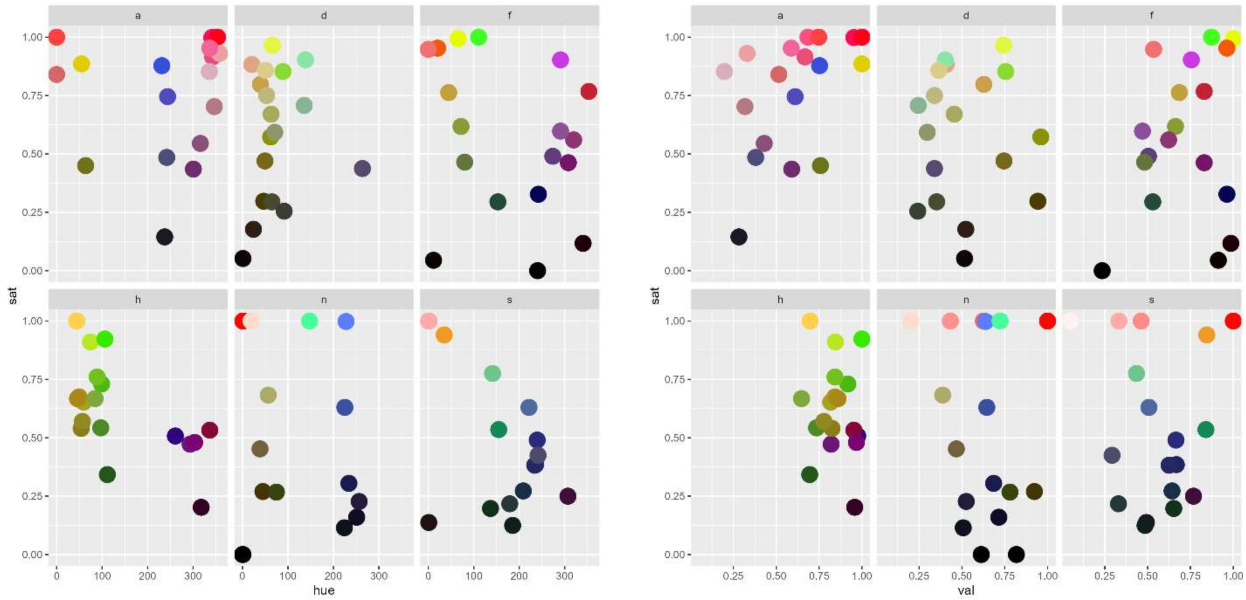

Figure 6 - The PECs on hue and value scales with saturation on the y-axis, Anger=a, disgust=d, fear=f, happy=h, neutral=n and sad=s

We see value and hue are significantly effective on changing the respective colour variable. The table show that different baseline emotions have different effect. For example, when comparing disgust to all other emotions, there is a significant difference in value for all emotions except sadness. Telling us, the value for sadness and disgust are much closer to each other than to the other emotions. If the table was to be all cyan, all the PECs would be completely different in all colour variables. However, to name one, fear has similar value and hue to all other PECs. We see that participants do make different colours, supporting H1.

5.1.2 Colour predicting emotion

To further investigate H1, we explore if the PECs can predict what emotion was presented during the colour-generating task. Since, the outcome variable, emotion, has 6 levels, we do this with a multinomial logistic regression model from R package NNET (Venables & Ripley, 2002). Since the pre-processing linear models did not show significance for any interactions or individual levels, we keep the model simple:

$$Emotion \sim Hue + Sat + Val$$

As all emotions have a value for all three predictions and are independent from each other. We can rephrase the question:

$$\ln\left(\frac{P(emotion = baseline)}{P(emotion = compare)}\right) = b_{intercept} + b_{hue} + b_{sat} + b_{val}$$

Running the model with ‘anger’ as baseline, we get:

Coefficients	Intercept	Hue	Sat	Val	Stand-ard Errors	Intercept	Hue	Sat	Val
Disgust	-0.647	-0.010	-3.850	6.968		2.002	0.004	1.563	2.186
Fear	4.465	-0.014	-4.398	1.393		1.712	0.004	1.549	1.807
Happy	6.574	-0.014	-4.463	-1.562		1.754	0.004	1.582	1.860
Neutral	4.907	-0.011	-4.095	-0.373		1.668	0.004	1.530	1.756
Sad	1.867	-0.007	-3.630	3.017		1.665	0.003	1.489	1.769
Residual Deviance: 320.7207									AIC: 360.7207

Table 3 - Coefficients and standard errors rounded to 3 decimals with ‘anger’ as baseline. Sat = saturation, val=value.

Using Wald’s two tailed z-test to inspect p-values:

Anger compared to	Intercept	Hue	Sat	Val
Disgust	0.747	>0.001	0.014	0.001
Fear	0.009	>0.001	0.005	0.441
Happy	>0.001	>0.001	0.005	0.401
Neutral	0.003	>0.001	0.007	0.832
Sad	0.262	>0.001	0.015	0.088

Table 4 - p-values rounded to 3 decimals with ‘anger’ as baseline. Sat = saturation, val=value. All the grey areas are insignificant findings.

To interpret the model output we take anger as baseline and compare it to the other emotions, such as disgust as shown in the example below:

$$\ln\left(\frac{P(anger)}{P(disgust)}\right) = -0{,}647 - 0{,}1 - 3{,}85 + 6{,}968$$

A one-unit increase in value is associated with a 6.97 increase in the log-odds of the faces displayed being ‘disgust’ versus ‘anger’ faces. One-unit increase in saturation is associated with a 3.85 decrease in log odds of the faces being ‘disgust’ versus ‘anger’ faces. Lastly, the log odds decrease with 0.01 for a one unit increase for hue comparing ‘disgust’ to ‘anger’.

Looking at the risk ratios calculated by e.g.:

$$(b_{hue})^e \ ,$$

Where b is the model’s coefficients from the tabular above.

	Intercept	Hue	Saturation	Value
Disgust	0.524	0.990	0.021	1061.978
Fear	86.900	0.986	0.012	4.026
Happy	716.440	0.982	0.012	0.210
Neutral	135.295	0.990	0.017	0.689
Sad	6.470	0.993	0.027	20.434

Table 5 - risk ratios comparing other emotions colour variables to anger’s.

Again with ‘anger’ as baseline, we see the relative risk ration for a one-unit increase in the variable hue is 0.99 for being disgust versus anger.

The remaining models for the different baseline emotions are calculated in the appendix (see 10.2). Here we have the general overview of which variables were significantly important for the different baseline models.

Colour explanation p-value below 0.05 & p-value above 0.05

Hue	Anger						
	Disgust						
	Fear						
	Happy						
	Neutral						
	Sad						
		Sad	Neutral	Happy	Fear	Disgust	Anger
Saturation	Anger						
	Disgust						
	Fear						
	Happy						
	Neutral						
	Sad						
		Sad	Neutral	Happy	Fear	Disgust	Anger
Value	Anger						
	Disgust						
	Fear						
	Happy						
	Neutral						
	Sad						
		Sad	Neutral	Happy	Fear	Disgust	Anger

Table 6 - showing between what emotion categories there is a significant difference in colour variable choice.

Next, we examine the changes in predicted probability associated with one of the colour variables, when the others are held constant at their mean value. Since all models had the same score of Akaike Information Criterion (Akaike, 1974) (see 10.2) and all possible plots looked the same. We here present the model with baseline, anger, predicted probability for different values of the colours’ variables falling under the different emotion categories:

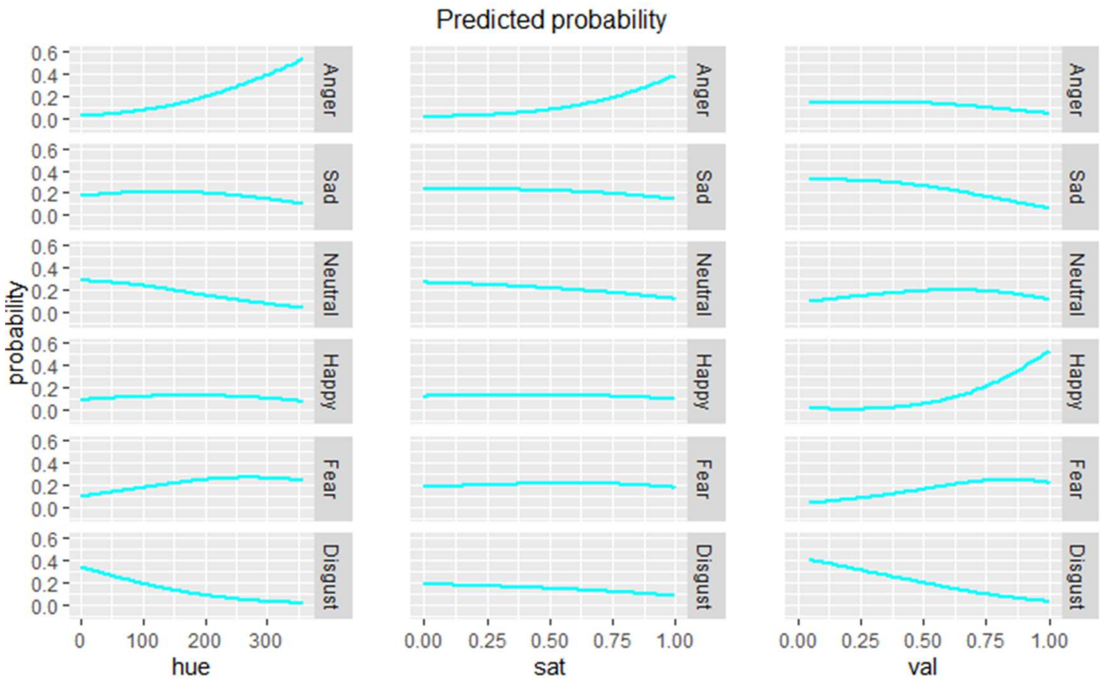

Figure 7 - showcasing the predicted probability of different colours being made while different emotions being visible during making trials with anger as baseline.

Note since we have a 6-category dependent variable our chance level in these plots is ~0.16, as they should sum up to 1. With this PEC description we move on to the experimental trial and participants consistency in colour choice. H1 is supported with participants diverse colour choice the hue and value variables. Saturation does not seem to play as big a role in predicting emotion.

5.2 Consistency (MO)

To see whether participants choose the PEC for the respective emotions in the colour-emotion matching task, we started by simply counting the number of times the participants choose congruently. Out of the 900 trials across the 18 participants, the participants chose congruently 702 times (78%) and chose incongruently 198 times (22%). A chi-squared goodness of fit test was then conducted on the congruency variable to test for H2. A significant difference was found between the frequency of congruently chosen PECs for participants (mean = 39, sd = 4.54) and the frequency of incongruently chosen colours for participants (mean = 11, sd = 4.54) with p-value <0.01, supporting H2.

5.3 Consistency in neutral trials (MO)

In the neutral trials, where participants either had the choice between neutral/congruent PECs or neutral/incongruent PECs, we started by looking at the relative choice counts for both choice combinations (see table 7).

	Total counts	percentage
Neutral/congruent trials		
Congruent	37	72,5%
Neutral	14	27,5%
Neutral/incongruent trials		
Incongruent	41	51%
Neutral	39	49%

Tabel 7 - Total number of times participants chose a congruent PEC or an incongruent PEC with respective percentages.

A chi-square goodness of fit test was conducted on both conditions to test for H3 and H4. A significant difference was found between the frequency of congruently chosen PEC (mean = 72%, sd = 30.5) and the frequency of neutrally chosen PEC (mean = 28.7%, sd = 30.5) with p-value < 0.01, supporting H3. No significant difference was however found between the incongruently chosen PEC (mean = 4.88, sd = 1.25) and neutrally chosen PEC (mean = 5.12, sd = 1.25). We therefor reject H4.

5.4 Preferences (MO)

5.4.1 Colour preference

In order to assess participants' preferred PECs, the times a PEC was chosen during the colour preference task was counted. In figure 8 the total number of a times a PEC was chosen for all participants is seen as well as the frequency of a PEC choice for each participant. The PEC for the emotion disgust (n = 359) was chosen the greatest number of times in total, followed by sadness (n =291), fear (n = 282), anger (n = 258), neutral (n = 248) and happiness (n = 182).

5.4.2 Emotion preference

We will now do the same for preferred emotional facial expressions. In figure 8 the percentage of the total amount of times an emotional facial expression was chosen is seen along with the percentage distribution of each participants chosen emotional facial expression. The emotional facial expression participants chose the greatest number of times was happiness (% = 91.7), followed by neutral (% = 59.5), fear (% = 49.5), sadness (% = 38), anger (% = 36.6) and disgust (% = 28.9).

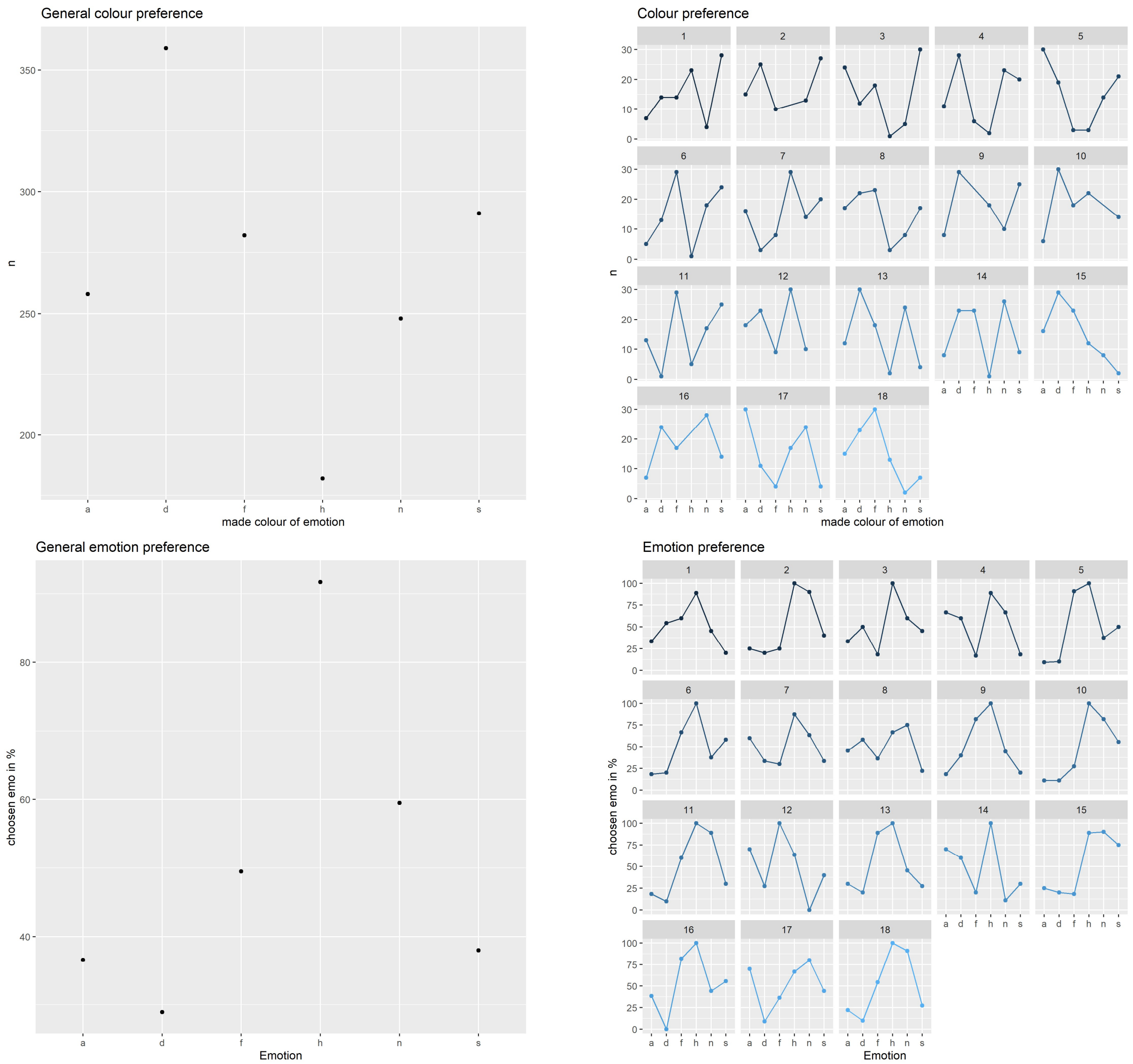

Figure 8 – Top left = number of times PEC was chosen in total. Top right =number of times a PEC was chosen individually. Bottom left = Percentage of the chosen frequency of emotional facial expression. Same across participants to the bottom right.

Interestingly, participants' emotional preference does not correlate to their colour preference as can be seen in table 8 of the preference scales.

Colour preference	Emotional facial expression preference
Disgust PEC	Happiness
Sadness PEC	Neutral
Fear PEC	Fear
Anger PEC	Sadness
Neutral PEC	Anger
Happiness PEC	Disgust

Table 8 – Preference scales based on general chosen frequencies of PECs and emotional facial expressions.

5.4.3 Preferences in the colour-emotion matching task

The number of times any given PEC was chosen in the colour-emotion matching task, is displayed in figure 9. The PEC for the emotion disgust was chosen the least number of times (n = 182) and the PEC for the emotion sadness (n = 209) was chosen the greatest number of times. The mean of PEC choice frequency was n = 196 with a standard deviation of 10,88.

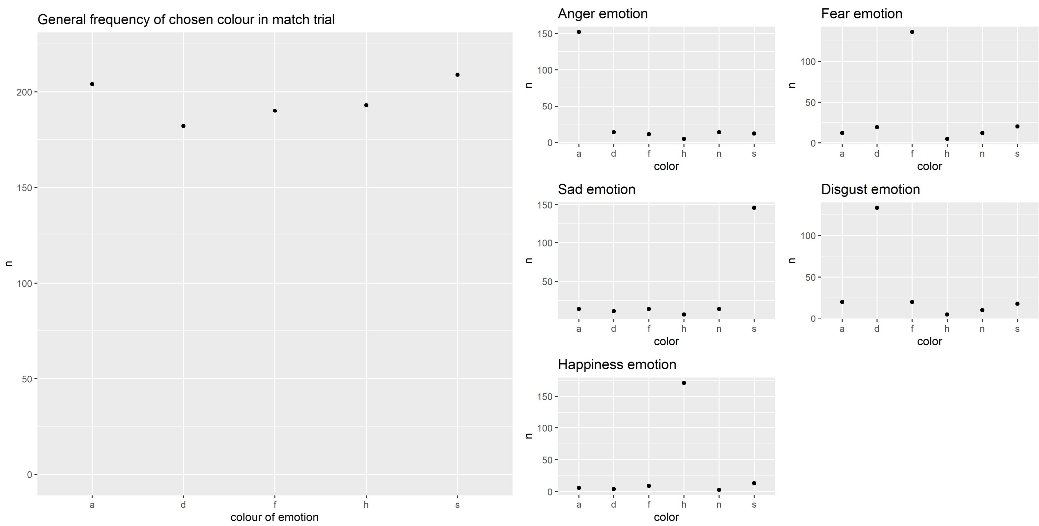

Figure 9 - Left - Frequency of PEC chosen in total for all participants. Right - Frequency of PEC choice given the display of a specific emotion.

6 Discussion

6.1 Colour choice (SK)

An assumption behind the overall hypotheses of emotions being coloured is there is a difference between the PECs. Following H1, we see people do produce different colours to the different face matrices.

When the colour variables are predicted by the emotion category, only hue and value had significant findings. The 'happy' and 'anger' PECs are convincingly significantly different from each other and the other emotion categories in hue. The intensity of a colour gave significant findings firstly for 'disgust' compared to all emotion categories leaving out sadness and secondarily for sad's PECs compared to happy and neutral categories. This leaves fear as not a distinct colour category in hue, saturation nor value, following da Pos et al.'s findings (2007), giving the impression different emotions have different hue values and to some degree different intensity values. Which follows the theory of passive and active emotions (e.g., sad versus happy) can be related to passive versus active colours (Sivik, 1974), (Xifu, 2003), (Ou et al., 2004), (Ou et al., 2004).

Following the significance table 6, we made predicted probabilities of what the likelihood of a colour falling under a specific emotion category was when the hue, saturation, value was investigated one by one. Figure 7 supports the previous findings that saturation does not change the loglikelihood extensively, since there is little to no difference of the probability distributions across emotion categories.

6.2 Consistency (MO)

Just by looking at the frequency of congruently chosen PECs, we see consistency in PEC choice for participants, as 78% of the times they were faced with matching a congruent or an incongruent PEC to an emotional facial expression, they chose the congruent PEC. This is also seen in the neutral/congruent trials where participants choose congruently 72,5% of the times they were faced matching a congruent or a neutral PEC to a facial expression. The p-values of the chi-square goodness of fit tests also reflects these finding showing a significant difference in the frequency of congruently and incongruently chosen PECs as well as between congruently and neutrally chosen PECs. These findings support H2 and H3, and thereby support the hypothesis of emotions being coloured.

The results also suggest the participants colour and emotion preference had no say in their choice when matching PECs to facial expressions in colour-emotion matching task, as they did choose congruently most of the times. The emotion and colour preference's lack of impact on colour choice is also reflected by figure 9, where the general frequency of chosen PEC is equally distributed. Furthermore, we also see when participants were presented with a face expressing any of the five emotions in the colour-emotion matching task, they chose the PEC associated to the emotional expression far more times than any of the other PECs. This further supports the idea that participants connect specific colours to specific emotions.

6.3 Neutrality of neutral PECs (MO)

No significant difference was found between the frequency of neutrally chosen colours and incongruently chosen colours, leaving us to reject H4. A possible explanation for the lack of difference could be the participants felt neither of the PECs they were presented matched the emotion expressed by the face on the screen. As it was a forced choice task, they therefore simply chose randomly between the two PECs. This would indicate rather than perceiving the two colours as incongruent and neutral, the participants perceived both colours as incongruent PECs, undermining the purpose of the neutral/incongruent condition.

Based on findings from a study done by Ebner et al. (2010), which found 87% of the participants were able to correctly identify a neutral emotion in facial expressions, the participants should be able to recognise the facial expressions in the colour-generating task as a neutral emotion.

Using the neutral PEC in neutral trial was based on the assumption that neutral is the lack of emotion as the distance to all other emotions' colours are somewhat equal. However, the PEC for neutral facial expressions may not have had the effect expected by a neutral colour, making the colour non-neutral even though it was based on a "neutral emotion".

The question then becomes how to characterize and measure a neutral colour. Based on the study mentioned earlier (Ou et al., 2004a, 2004b), which found a connection between arousal and colour-emotion matching, it would be expected a neutral colour would evoke a higher arousal than colours matched to passive emotions and lower arousal than colours matched to active emotions. As a neutral emotion is neither passive nor active. An arousal trial, where participants would have to choose witch colour, they feel arouses them the most, could therefore be implemented, to control for arousal. It would then be expected the neutral colour would be right in the middle on an arousal scale for it to be an actual neutral colour.

Making sure the neutral PEC is indeed a neutral colour is not as straight forward as first expected. In future research one could instead consider having a condition where participants are shown two incongruent colours rather than a neutral and an incongruent colour. Furthermore, instead of making forced choice tasks participants could an option stating: "None of the colours match the facial expression". It would then be expected then faced with the option between two incongruent PECs, participants would choose none of the above. It would still be expected, participants choose congruently when faced with the choice of a congruent and incongruent PEC.

6.4 Future research (MO)

Based on findings made by Ebner et al. (2018), faces displaying certain emotions may be perceived as more attractive than other. Though we had taken measures to minimize attractiveness influencing which colour participants chose in the colour-emotion matching trials, attractiveness' effect on emotional colour choice would however still be of interest for further research. In addition to this, it could also be interesting to examine if sexuality affects the emotional colour choice. If this was the case, one could imagine that a heterosexual woman would choose her most preferred colour, or perhaps she might choose colour based on saturation and arousal, when presented with a male face displaying any emotion.

Nevertheless, participants where consistent in their colour choice and chose colours congruent to the emotional facial expression they were presented with, indicating an effect of colour-emotion connection. Further evidence supporting this effect comes from a study by Jonauskaite et al. (2021). The study wanted to examine whether there was a difference between the conceptual experience of colour and the immediate perceptual experience of colour. This was done by having a group of congenitally red-green colour-blind men and a group of non-colourblind men associate 12 colours (presented as terms or in patches) with 20 emotion concepts as well as having them rate the intensities of the associated emotions. They found participants associated similar emotions whether they were colour-blind or not and regardless of the way they were presented (either in terms or in patches). These findings indicate the conceptual experience of colour is sufficient for colour-emotion association in adults. Furthermore, these findings indicate that this colour-emotion association is so strong that even immediate colour perception is not necessarily needed for making this connection between colours and emotions. Colour-emotion association has also been detected in early childhood. However, there has been found a difference between which colours adults and children associate with specific feeling, with children under the age of five associating red with happiness and blue with anger rather than red with anger and yellow with happiness which was the case with adults (Zentner, 2001).

This suggests that colours and emotions are linked together from an early age, but exactly which colours are associated with which emotions change over time (Terwogt & Hoeksma, 1995). The change in the combination of colour-emotion associations could be due to exposure to certain colours in certain contexts throughout life. As we also know that colours are used in different contexts depending on culture, also reflected by natural language as mentioned in section 1.1. Further research in the combination of colour-emotion association across age as well as cross-culturally would be of great interest.

6.5 Shortcomings (SK)

As mentioned earlier colours and emotions are multifaceted and multidimensional, along with our experience quantifying a spectrum is hard to do and grasp. As an add on to the (Terwogt & Hoeksma, 1995) study, we gave the participants the opportunity to choose the specific colour they felt fitted instead of a prechosen one. Allowing the participants to use the entire HSV colour space as they saw fit. However, we used faces with the best examples of the categorized emotions and not a wide spectrum of emotions only of people. This was to make our analysis more approachable, but it also limits our interpretation since there are many ways to be happy and many nuances of colours. For future work a spectrum of emotions, for example the dynamic FACES database (Holland et al., 2018), would be interesting to add to investigate if the colours follow the complex flow of emotional facial expressions.

The experiment had its flaws with latency when loading the faces matrices in the first task, why we also left out reaction time as a measure. However, it would be interesting to see what influences participant's decision making by using mouse or eye tracking. A possible add on with EEG and could investigate whether the recognition time of emotions are aided when a congruent colour is present. Furthermore, we had a coding error which resulted in the participants being shown the congruent and neutral trials a different number of times in the emotion-colour matching task. This is very unfortunate, however the cumulative times the combinations were shown varied with a maximum of 4 times. The error was fixed for 8 of the participants, so this did not affect our analysis further. See 10.3.1 for visualisation. Due to another coding issue all participants were shown the same order of PEC combination for (e.g., anger-disgust followed by anger-sad). For future reference it would be optimal to randomize this order completely. Based on oral feedback from participants, we had at least two participants who deliberately choose the same colour repeatedly due to boredom in the colour-emotion matching task. As we had 60 trials per person for the consistency conditions (see 10.3.2) it would be worth considering lowering the number of trials in this condition or adding breaks to keep participants engaged. Lastly, given the low sample size (n=18) our study has low statistical power.

Given previous research as well as the results of our experiment discussed above, it seems that there is evidence for emotions being coloured. Therefore, using certain colours to invoke certain feelings seems like a reasonable method, whether it is in marketing, traffic safety or any other context with the goal of conveying a message quickly in a world where everyone is fighting for our attention. However, given shortcomings of our experiment, a replication of this study adjusting the experimental design to accommodate these shortcomings would be needed for the experiment to support the overall hypothesis of emotions being coloured. All for making an evidence paved way from colours to emotions.

7 Conclusion (MO)

The aim of this study was to examine whether emotions are coloured by testing for significant differences in several sub-hypotheses. Based on the significant difference in congruently and incongruently chosen colours, the emotion and colour preference's lack of influence on colour choice in the colour-emotion matching task, the predictability of emotions from colour-attributes as well as distinctiveness in colour choice, it seems that colours and emotions are linked together in a non-arbitrary way. However, due to coding errors, low statistical power as well as doubt of the reliability of the neutral PEC, replicating the study with a larger sample size and with adjustments to the experimental design as well as further research in the relationship between colours and emotions is needed in order to support the hypothesis of emotions being coloured.

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