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**Colour fluctuations in grapheme-colour synaesthesia: The effect of mood
and mood disorders**

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Abstract

Synaesthesia is a condition that gives rise to usual secondary sensations (e.g., colours are perceived when listening to music). These unusual sensations tend to be reported as being stable throughout adulthood (Simner & Logie, 2007) and the consistency of these experiences over time is taken as the behavioural hallmark of genuineness. Our study looked at the influence of mood states on synaesthetic colours in synaesthesia. In Experiment 1 we recruited grapheme-colour synaesthetes (who experience colours from letters/digits) and elicited their synaesthetic colours, as well as their mood and depression states, in two different testing sessions. In each session, participants completed the PANAS-X (Watson & Clark, 1999) and the BDI-II (Beck, Steer, & Brown, 1996), and chose their synaesthetic colours for letters A-Z from an interactive colour palette. We found that negative mood significantly decreased the luminance of synaesthetic colours. In Experiment 2 we showed that synaesthetic colours were also less luminant for synaesthetes with anxiety disorder, versus those without. Additional evidence suggests that colour saturation, too, may inversely correlate with depressive symptoms. These results show that fluctuations in mood within both a normal and clinical range influence synaesthetic colours over time. This has implications for our understanding about the longitudinal stability of synaesthetic experiences.

Introduction

Synaesthesia is an inherited condition that causes unusual secondary sensations. For example, synaesthetes may see colours when smelling odours (Day, 2013), or they might experience tastes when hearing words (Ward & Simner, 2003) or listening to musical notes (Beeli, Esslen & Jäncke, 2005). These experiences feel intrinsically normal to the synaesthete, who will have experienced them since childhood (at least in the case of *developmental* synaesthesia, the focus of the current article). Synaesthesia is found in at least 4% of the population (Simner et al. 2006), and two recent genome-wide studies have identified genetic regions of interest on chromosomes 2, 5, 6, and 12 and 16 (Asher et al., 2009; Tomson et al., 2011). Synaesthesia is a multi-phenotypic condition depending on which modalities are merged (e.g., sound with colour, taste with shape etc.), but one of the most common forms is *grapheme-colour synaesthesia* (Simner et al., 2006) in which colour-experiences are triggered by reading, hearing or thinking about graphemes (letters or numbers). In scientific parlance (Grossenbacher & Lovelace, 2001) graphemes would be the

“inducer” stimulus in this variant, and colour would be the “concurrent”, and we shall use this terminology throughout our paper. In this article we will look at how synaesthetic concurrents of colour can be influenced by the mood states of synaesthetes.

Since one person cannot access another’s perceptual experiences, synaesthesia researchers rely on measuring the behaviour of synaesthetes, or their neurophysiological responses, but they also elicit first person accounts. When adult synaesthetes report their concurrent sensations for any given list of inducers, these tend to be highly consistent over time. In other words, a given inducer (e.g., the letter A) tends to elicit the same synaesthetic concurrent (e.g., the colour red) for any given synaesthete in repeated testing. Indeed, synaesthetic sensations are often thought to be consistent *by definition* throughout the adult lifespan and this consistency-over-time is taken as the behavioural hallmark of synaesthesia in genuineness testing (see Johnson, Allison, and Baron-Cohen, 2013 for review, and Simner & Bain, 2013 for how this constancy develops in childhood). In a typical genuineness test of synaesthesia (e.g., Baron-Cohen, Wyke & Binnie, 1987), synaesthetes are required to report their synaesthetic associations for a stimulus list (e.g., a list of letters), and must be significantly more consistent in a retest compared to a group of nonsynaesthete controls, who are asked to invent analogous associations (i.e., to make up colours for the 26 letters and then recall these later). Hence, synaesthetes tend to be highly consistent and have been shown to out-perform controls even when tested over far longer time intervals, and even when controls are given monetary incentives to perform well (e.g., Ward, Simner & Auyeung, 2005). For example, synaesthete EP was 100% consistent in her colours for a set of words across one year, compared to a nonsynaesthete control who was just 17% consistent over two weeks (Baron-Cohen et al., 1987).

Research into synaesthesia has relied heavily upon this consistency feature because it is the standard by which synaesthetic status is traditionally verified. But although virtually every synaesthete described in the literature has been shown to be significantly more consistent than controls, they are not necessarily 100% consistent. Grapheme-colour synaesthetes in a study by Simner et al. (2006) for example, had consistency scores that ranged from 73-100%. All were considered synaesthetes because they were each significantly more consistent than controls. Nonetheless, this variation in consistency shows there can be a degree of impermanence in synaesthetic sensations, which is rarely talked about (but see Simner, 2012; Cohen Kadosh & Terhune, 2012; Eagleman, 2012). In the current paper we ask

what might account for variations in reported synaesthetic colours, and we begin by briefly exploring several theoretical possibilities below.

We first point out that inconsistently reported synaesthetic associations might be due to difficulties in *reporting*, rather than to inconsistency in the experience itself. For example, a synaesthetic colour that lies on the border between the two colour categories of, say, red and brown (i.e., a maroon-like colour) might be described as red on one occasion but brown on another, making the association appear inconsistent when it is in fact not. Alternatively, it might be difficult for the synaesthete to identify the sensation at all. Lexical-gustatory synaesthete JIW, for example (who experiences floods of taste in the mouth when reading words) experiences tastes he cannot always identify, and this too can lead to reporting discrepancies (e.g., one taste was reported as Sugar Puffs[®] breakfast cereal on one occasion but Rice Krispies[®] breakfast cereal on another -- even though the taste itself had not changed; Ward & Simner, 2003). Inconsistencies in reporting might also arise when a single inducer has more than one concurrent: grapheme-colour synaesthete JM, for example, reports that her letter L is “both black and yellow. Not a mix of those two, it's just both simultaneously” (personal communication). Again this might artificially lower consistency scores if JM chooses to report yellow on one occasion but black on another. Indeed, some synaesthetic concurrents are so highly complex that it is almost inevitable for inconsistencies in reporting to arise. Consider synaesthete MJS for example, who has sequence-personality synaesthesia (in which letters, numbers and other sequences are synaesthetically imbued with human qualities; Simner, Gärtner & Taylor, 2011). Since personality has many facets, personality concurrents are necessarily complex, and this can cause misleading reports. MJS for example first described the number 2 as ‘someone who gets things done’, but later as ‘a quiet type’ (Simner et al., 2011). This appeared inconsistent until she was asked again four years later, at which point she described the personality more fully as a “good quiet little sort, can be counted on. Deals with it. Ideal employee’ (Simner et al., 2011; pg. 293). Only then was it clear that the concurrent itself never changed, even though selective reporting had made it appear inconsistent. Finally, it is also possible that different facets of a concurrent are more prominent at different times.

In all instances above, the nature of the synaesthetic concurrent was unchanged over time but simply reported differently. It is possible, however, that concurrents themselves do change over time. This issue has been almost entirely overlooked in the literature and is poorly understood. In this paper we ask how synaesthetic colours might change from day to

day, particularly under the influence of mood. Human moods or emotional states change across points in time, and it is therefore reasonable to ask whether these mood changes influence synaesthesia in some way. There are several reasons to believe they might. First, mood states can affect cognition, reasoning and attention (Oaksford, Morris, Grainger, & Williams, 1996; Compton, 2003; Wadlinger & Isaacowitz, 2006; Blanchette & Leese, 2011; Pessoa, 2008) so may indirectly influence synaesthesia simply because attention on the inducer, for example, is necessary for synaesthetic colours to be triggered (for review of attentional influences on synaesthesia, see Rich & Mattingley, 2013). Alternatively, changes in mood might influence synaesthetic experiences more directly, and if this is true, it could cause fairly regular fluctuations in synaesthetic experiences. If mood state does influence synaesthetic concurrents, we ask what form this influence might take.

To answer this, let us briefly review what is known about how mood and colour are related, both in synaesthetes and nonsynaesthetes. In synaesthesia, there have been a small number of case reports of emotion as the direct inducer for a synaesthetic experience. One historical account describes case E, for whom “experiences are emotionally colored in a literal sense” (Cutsforth, 1925; p 529). This descriptive account suggests that E experienced a range of stimuli (odours, sounds, memories) in terms of the colour of their emotional valence: pleasant stimuli were often blues, reds, and yellows, while unpleasant stimuli were often greens and browns. In more detailed account in the modern literature, Ward (2004) described GW, who reports synaesthetic colours on the presentation of emotionally valent words. When presented with a list of names for example, she experienced colours more for the names of people she knew (and therefore had emotional connections with) than of people she did not know. Common nouns, too, triggered colour according to their emotional value: words that were highly emotive such as ‘love’ elicited synaesthetic colours more often than neutral stimuli, such as ‘chair’. There was also an association between emotions and the *nature* of the synaesthetic colour: positive emotive words had a lighter and more saturated colour, and more negative words were darker and less saturated. Ward (2004) therefore concluded that GW’s inducer had an emotional component distinct from lexical qualities of the words themselves, and that this linked high luminance and saturation to positive emotional valence.

Mood and emotional state are also associated with colour qualities for even the general population. Studies have shown that different colour qualities (i.e., of hue, saturation and luminance) are linked to different mood states. Manav (2007) found that subjects associated the colour yellow for example with more negative emotional adjectives when its

luminance was lower (e.g., *boring, anxious, depressive*). Children too are already able to express coherent shared emotional responses to colours at the age of 5-6 years. When asked “How does this colour make you feel?”, they tend to give positive emotions to bright colours (e.g., pink, blue, red) and more negative emotions to dark or achromatic colours (e.g., brown, black, grey; Boyatzis and Varghese, 1994). A similar finding has been replicated in the adult population (Hemphill, 1996).

One final set of studies suggests again that mood variances may influence colour associations -- this time for clinical mood states -- and they can even influence the very nature of colour perception itself. For example, Bubl, Kern, Ebert, Bach, and Tebartz van Elst (2010) found that participants with major depression have altered perception of luminance (see below). Major depression is a common mood disorder which affects approximately 10% of the population at any one time (Office for National Statistics, 2000) and whose predominant symptom is persistent low mood (Hammen, 1997) or a lack of joy (Peters, Nicolson, Berkhof, Delespaul, & de Vries, 2003). In this sense, major depression might be considered an extreme extension of sadness, and indeed, both involve overlapping brain regions (in both instances, negative mood state is associated with decreased activity in right prefrontal cortex and increased activity in the subgenual cingulate; Mayburg et al., 1999). Given our interest in mood, it is relevant to consider how depression or other clinical mood states might also relate to different colour qualities. Bubl et al. (2010) looked at vision in participants with major depression by assessing their contrast gain. Contrast gain refers to the ability to differentiate objects from their surroundings based on their luminance contrast; an example of high contrast, for example, is the appearance of black letters on white paper. Bubl et al. (2010) evaluated the ophthalmologic response of the retina when healthy or depressed participants viewed stimuli of differing contrasts. They found significantly lower retinal contrast gain in depressed patients, suggesting that when people are depressed, they are less able to perceive luminance contrasts in the visual world. The same researchers also showed that people with depression had lower contrast discrimination performance in a behavioural task (Bubl, Tebartz van Elst, Gondan, Ebert & Greenlee, 2009). Finally, Carruthers, Morris, Tarrier, and Whorwell (2010) found that people in certain clinical mood states are also drawn to different types of colours in a systematic way. They asked healthy participants, anxious participants, and participants with depression to select their colour preferences from a colour palette. Both depressed and anxious individuals were more drawn to the achromatic end of the spectrum – particularly to the colour grey. This suggests that low clinical mood states may

relate not only to changes in luminance detection, but also to lower saturation (i.e., ‘chroma’) in colour preferences.

The review above has shown that mood states are systematically linked to colour in three different populations: healthy individuals, clinical population (with depression or anxiety) and synaesthetes. Healthy individuals associated negative emotional moods with low saturation and luminance, both as children and adults. Depressed and anxious individuals are drawn to low saturated colours, and the former experience poor contrast sensitivity to luminance. Finally, synaesthetes who are specifically triggered by mood states as inducers experience lower saturated/ luminant colours for negative valence words.

The current study

Above we reviewed the role of mood/emotion in synaesthesia and in colour associations more generally. In this study we explore whether it can also play a role in variations in synaesthetic colours, even for a type of synaesthesia not generally linked to emotional qualities. Grapheme-colour synaesthesia is considered on the whole to be (a) consistent over time, and (b) devoid of emotional influences (at least in the *triggering* of colour; see also Callejas, Acosta, & Lupiáñez, 2007 and Hochel et al., 2009 for a discussion of how synaesthetes might appraise the un/pleasantness of their synaesthesia, once triggered). Here we ask whether changes in mood state can nonetheless influence grapheme-colour synaesthesia, to bring about subtle changes in synaesthetic concurrent colours over time. In Experiment 1, we examine day-to-day changes in mood in a non-clinical population of synaesthetes. In addition, since transient sadness and major depression recruit similar brain regions and have similar impact on the association of colour with mood, we will also consider the role of non-clinical depressive traits (Experiment 1) and clinical anxiety disorder (Experiment 2). From our review of colour in clinical/nonclinical mood states above, we predict that positive mood states may be associated with more luminant/ saturated colours, while negative mood states may associate with darker/ less saturated colours. Given these strong predictors for saturation and luminance, we focus on these two features in the current paper, to the exclusion of hue (but we consider the impact on hue in a subsequent paper, Kay, Carmichael & Simner, in prep).

Experiment 1

In the study below we elicited synaesthetic colours for letters from a group of grapheme-colour synaesthetes. Each synaesthete selected their colours from an on-screen colour palette, and did so twice, separated by a period of approximately three weeks. Participants were instructed to enter each session only when in a naturalistically different mood: positive on one occasion and negative on another. We confirmed their mood levels using mood questionnaires, and then compared their synaesthetic colours across the two states of mood, in terms of changes in saturation and/or luminance. We used questionnaires to evaluate both non-clinical mood state, and depressive traits. We predicted that the positive mood state would be associated with higher saturation and luminance in synaesthetic colour, while the negative mood state would be linked to lower saturation/luminance levels.

Methodology

Participants: Participants were 24 native English-speaking grapheme-colour synaesthetes who experience coloured letters (mean age 45.8 years, st. dev =13.0; 21 females). Participants were recruited from the Edinburgh-Sussex Database of Synaesthete Participants, and had previously been verified as genuine cases using the ‘gold standard’ measure of consistency over time (e.g., Baron-Cohen et al., 1987). In this previous verification stage, participants were given synaesthetic triggers as stimuli (in this case, a list of 26 letters) and were required to verbally report their synaesthetic colours. They were retested without warning after approximately two months, and their mean consistency score was 91.7% (st. dev = 12.6). This performance was significantly higher than non-synaesthete controls (n=40; from Simner et al., 2006) who were only 36.2% consistent (st.dev = 13.8; $t=16.1$, $df=62$, $p<.001$). Synaesthete participants were paid £20 for their involvement in our main study, which was given ethical approval by the local ethics board at the University of Edinburgh. Since their genuineness was established as part of other studies, this took place some time before the current study -- in some cases, several years earlier -- and so would not have influenced performance in the current task (in which synaesthetic colours are also elicited).

Materials: To remove geographical restrictions on testing, our experiment was generated via an online testing platform, created using a survey builder website. The

experiment had three components: a test of mood (the Positive and Negative Affect Schedule - Expanded form; PANAS-X; Watson & Clark, 1999), a test of depressive traits (the Beck Depression Inventory – II (BDI-II; Beck et al., 1996) and a test to elicit synaesthetic colours. These are described in brief below.

PANAS-X: This mood test requires the participant to read 60 emotive words, such as ‘distressed’ or ‘enthusiastic’. Participants were asked to rate how relevant each word was to their current mood state on a 5-point scale, ranging from “not at all” to “extremely”, with one rating per word. For the present study, we focussed on the PANAS-X positive and negative affect scales. Each scale is made up of 10 emotive words (e.g., *enthusiastic* and *distressed*, for positive and negative affect respectively)¹. Stimuli were presented in an order stipulated by PANAS-X, which ensures that words are well distributed and not clustered into emotion subgroups.

BDI-II: The BDI-II (Beck et al., 1996) is designed to determine the presence and level of depressive symptoms. In this test, participants were presented with 21 sets of statements, each set comprising four sentences which are similar but represent a decline in well-being from the first statement to the last. For example:

- I do not feel sad
- I feel sad much of the time
- I am sad all the time
- I am so sad and unhappy that I can’t stand it

Synaesthetic letter-colour test: In this sub-test, participants were presented with each letter, one at a time in a random order, and were required to select their synaesthetic colour from an accompanying electronic colour palette. This palette showed colour graduations within a square frame, where hue changes horizontally, and saturation changes vertically. Participants can select a colour by clicking anywhere in the frame. Luminance was manipulated by a separate ‘luminance bar’

¹ The words within the PANAS-X are also further divided into additional subgroups: four negative (*fear, hostility, guilt, sadness*) three positive (*joviality, self-assurance, attentiveness*) and four neutral (*shyness, fatigue, serenity, surprise*). However, given the small number of words in each sub-group, and our relatively small sample size, we do not consider these subgroupings for the purpose of the current study.

placed vertically to the right of the palette, which could be dragged up and down using the mouse. The selected colour is displayed in a separate display below the palette, and encoded numerically to quantify its hue, saturation, and luminance.

Procedure: Participants were informed they would be taking part in an online study which they were to complete by visiting our website twice (i.e., at two separate times). Participants were asked to log onto the website to take part in Session 1, but in particular, only when they felt in a specific mood state. Half the participants were asked to take part in the first session when they felt in a positive mood and the other half when they felt in a negative mood. This is the first time a mood manipulation of this type has been used when testing synaesthetes. The participants were informed that the test would take approximately an hour for each session, and that they were to complete all elements of the test during each session. This was to ensure we had their colour responses for a given session time-linked to their mood/depressive responses.

The first page of the survey informed participants of their ethical rights. Participants then consented with a check box and provided their name, data of birth and date of completing the survey before proceeding to the study. Participants first completed the PANAS-X, then the BDI-II, then the colour-palette test. The palette was accessed using a link to an accompanying webpage. Participants selected their colours for letters and transferred the numeric codes into the main survey screen. After this test was completed, the session ended. Participants were contacted three days later with the link to the second survey, asking them to be in the alternative mood state when entering it. Therefore, those who had completed the first survey in a positive mood were asked to be a negative mood, and those who had completed the first survey in a negative mood were asked to complete the second survey in a positive mood. The second survey was identical to the first survey.

Although the participants were not explicitly informed that mood was the factor under investigation, they were asked to be in a particular mood state to complete each test. During debriefing, participants reported they found this instruction straight-forward, and we took this approach to profit from natural variances in mood states (rather than to attempt to vary mood states artificially within the test itself – see discussion). On average, participants' two testing sessions were separated by 23.3 days (st. dev. = 14.0).

Results

Coding

Each test was coded prior to data-analysis as follows:

PANAS-X: Responses to each word (e.g., *distressed*) are coded 1 to 5, from “not at all” and 5 to “extremely”. Our analyses are based on the positive and negative affect scales, each of which contains 10 words. The score for each scale is calculated as the mean score across the words in each list, giving a maximum possible score of 5.0 (with 1.0 as the minimum). For example, a participant might achieve a total of 32 points by summing each Likert response across the 10 words in the positive affect scale. Their mean final score for this scale would therefore be 3.2.

BDI-II: The BDI-II is scored by first coding each answer according to the level of response: each level is given a score of 0-3, with 0 being the neutral statement and 3 being the most negative statement. The final score is generated by adding these sub-scores together to get overall depression score, with a maximum possible score of 63 (with 0 as the minimum).

Synaesthetic colour-letter test: The participants’ colour choices generated a unique 6-digit alphanumeric code, which represents its hue, saturation and luminance levels. The values for luminance were averaged across all 26 letters, for each subject, and the same process was also used for saturation data.

In our analyses below, we first examine whether we successfully manipulated mood across our two sessions and then examine the influence of mood on synaesthetic colours, first by luminance and then saturation. Prior to all analyses, we first checked the distribution of data using a Kolmogov-Smirnov test, and used parametric and nonparametric analyses as required.

Analyses

Did We Successfully Manipulate Mood?

We compared mean scores for negative affect and then positive affect across our two conditions: *Requested positive mood condition* vs. *Requested negative mood condition*.

Distribution curves show that negative but not positive affect scores were non-normally distributed and so we use a Wilcoxon signed rank test and a paired sample t-test, respectively. Table 1 shows that, as anticipated, the *Requested negative mood condition* generated higher negative affect scores than the *Requested Positive mood condition* ($Z=-3.8$; $p<.001$), as well as lower *positive* affect scores ($t=9.4$, $df=23$, $p<.001$), and higher BDI-II depression scores ($Z=-4.7$; $p<.001$).

Table 1

	Requested Negative mood Condition	Requested Positive mood Condition
Mean Negative Affect	2.1	1.3
Mean Positive Affect	2.2	3.3
BDI-II	15.7	5.0

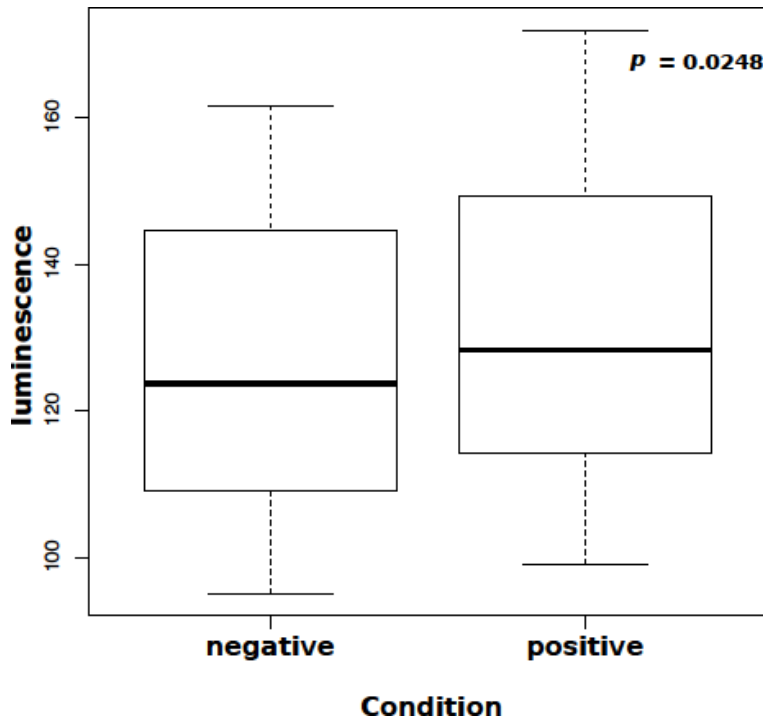
Table 1. Mean scores across testing conditions in Negative/Positive affect (from the PANAS-X test) and in depressive traits (from the BDI-II test). There were two testing conditions: participants were instructed to take part when their mood was either low (Requested negative mood condition) or high (Requested positive mood condition). BDI-II depression scores are ‘Minimal’ below 14, and ‘Mild’ at 14-19.

Since scores indicate participants were in the appropriate mood states within each testing condition, we assume henceforth that differences across conditions in synaesthetic colour reflect changes in mood. (We therefore also henceforth refer to our *Requested positive/negative mood conditions* as simply our *Positive/Negative mood conditions*).

Does Mood Influence Synaesthetic Colours?

Below we examine the synaesthetic colour chosen by participants in each mood condition, first by saturation data then by luminance data. The mean saturation of synaesthetic colours was 161.6 in the Positive mood condition (st.dev. = 28.1) and 159.6 in the Negative mood condition (st. dev.= 30.1), showing no significant difference ($t=.46$, $df=23$, $p=.7$). However, the mean luminance of synaesthetic colours was 131.5 in the Positive mood condition (st.dev = 21.4) and 127.4 in the Negative mood condition (st. dev.=20.8; see Figure 1), and this difference was significant ($t=2.4$, $df=23$, $p=.0248$; see Figure 1).

Figure 1. Mean luminance of synaesthetic colours from grapheme-colour synaesthetes in positive versus negative mood. The lower and upper box limits first and third quartiles, and bars delimiting lowest and highest values.



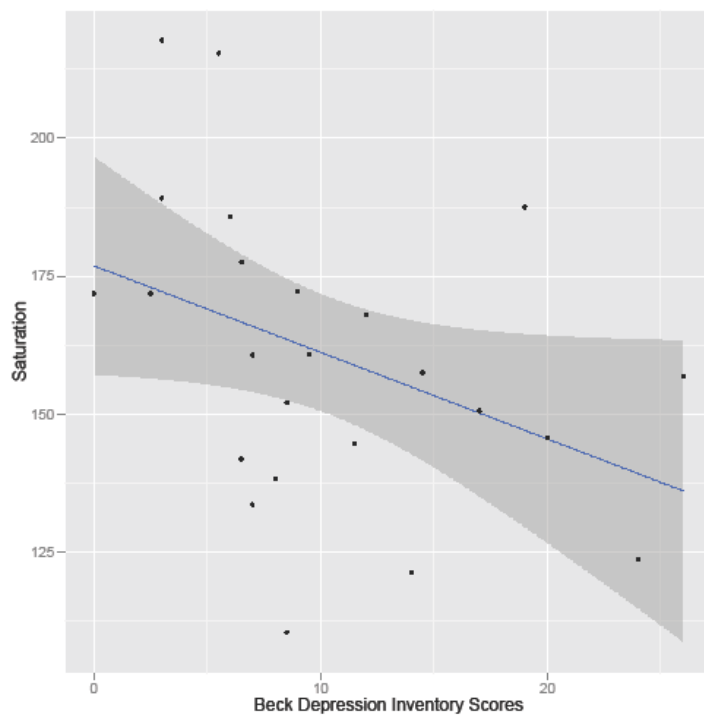
What element of mood causes changes in synaesthetic colours?

Having established that changes in synaesthetes' moods affect their synaesthetic colours, we sought to explore what elements of mood were responsible: positive affect, negative affect, or depressive traits. For this we ran a simultaneous entry multiple regression analysis using all three as predictor variables, with luminance as the outcome variable in one model, and saturation in another. Our predictor and outcome variables were each calculated for each subject as the mean across both their testing sessions. We point out that our sample size is small for regression modelling and so our conclusions here are presented as tentative.

Despite our group effect above, there was no significant model relating mood/depression scores as predictors for our luminance data ($F= 1.1$, $df=2$, $p=.4$). However, for our saturation data, we found a near-significant model ($F=2.6$, $df=2$, $p=.08$). Within this model, only one predictor approached significance, and this was depression scores from the BDI-II ($\beta=-.60$, $t=-1.8$, $p=.08$) which was negatively related to the saturation of the synaesthetic colour. In other words, as depressive tendencies increase, the synaesthesia's

saturation tended to decrease. We illustrate this relationship in the scatterplot shown (see Figure 2) with best-fit line shown.

Figure 2. Scatterplot showing a near significant ($p=.08$) inverse correlation between the depressive traits of grapheme-colour synaesthetes, and the saturation of their synaesthetic colours. Depressive traits are scored on the Beck Depression Inventory – II. The graph also shows the best-fit line and 95% confidence interval surrounding it.



Discussion

Our study has shown that the synaesthetic colour experiences of grapheme-colour synaesthetes are influenced by their mood. We requested that participants completed our tests in two different mood states, and confirmed those mood states with mood questionnaires. We found that participants reported significantly less luminant synaesthetic colours in the negative mood state compared with the positive mood state. We also found a suggestion that the saturation of synaesthetic colours might be influenced by depressive traits: there was a trend towards lower saturation when depressive traits were higher. In the study below we

extend this finding to a clinical mood disorder, and we also address a methodological concern arising from Experiment 1.

Experiment 2

There were a methodological concern arising from Experiment 1, which we aim to address in a second study here. Our concern is to verify that we did not induce strategic effects in our first study simply by having asked participants to be in a particular mood. Our method above had advantages because it allowed relatively naturalistic mood differences, but it also may have alerted our participants to the nature of our investigation. In the study below, therefore, we test the effect of mood without drawing attention to this feature. In Experiment 2, we screened a large random sample of the population to identify the synaesthetes among them, and we also had participants fill out a health questionnaire. Embedded in the questionnaire was an option to indicate whether the participant was suffering from anxiety disorder. Anxiety disorder is a condition in which sufferers experience generalised worry and anxiety, not (necessarily) connected to recent events. Commonly regarded as belonging to a spectrum of mood related disorders, symptoms include feelings of threat, irritability and tension (Tyrer & Baldwin, 2006).

Methodology

Participants: Our participants were 34 English-speaking grapheme-colour synaesthetes (mean age = 21.9, SD = 5.8, 20 females), six of whom had (self-reported) anxiety disorder (mean age 20.8, S.D. 2.8; 3 females) and the remaining 28 reported did not (mean age 22.1 years, S.D. 6.3; 17 females). Participants were recruited via a large scale screening of 2847 members of the general population (mean age 28.4, SD= 14.3; 1530 female) for grapheme-colour synaesthesia (see Carmichael et al., in review, for further information). Our subjects were verified as synaesthetes using the objective test described below (see Materials and Procedure).

Materials and Procedure: Our procedure allowed us to identify a group of randomly sampled synaesthetes, tested objectively, and also to verify which of those synaesthetes had anxiety disorder and which did not. Our procedure also allowed us to determine our

synaesthetes' grapheme-colours, so that we could then compare these across individuals with and without anxiety disorder.

All 2847 participants (including the 34 synaesthetes that would ultimately be found among them) were sent to an online testing website where they completed a 2-stage test. The first stage was a health questionnaire in which participants indicated (inter alia) whether they did, or did not suffer from anxiety disorder. This health questionnaire listed 24 conditions in total (e.g., anxiety disorder, asthma, migraine) meaning that our focus of interest was sufficiently hidden.

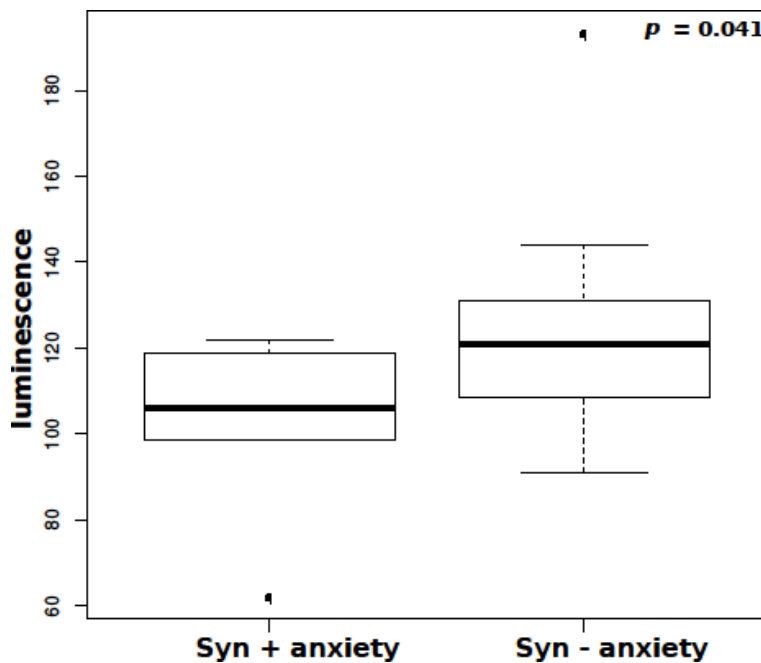
The second stage of testing was a short questionnaire which described grapheme-colour synaesthesia and asked whether participants thought they might experience this. For those who responded in the affirmative, an objective test followed. As in Experiment 1, this objective test for synaesthesia was based on consistency-over-time as the behavioural hallmark of synaesthesia. Also as before, synaesthetes were identified as those who were significantly more consistent than nonsynaesthete controls. Our consistency test was this time performed via the online diagnostic site synesthete.org (see Eagleman, Kagan, Nelson, Sagaram & Sarma, 2007 for methods, also Carmichael et al., in review). This site not only verifies synaesthesia, but also gathers synaesthetic colours in a way that can later be analysed according to saturation and luminance values. In this battery, graphemes were presented three times each in a randomised order and participants were required to select their synaesthetic colour for each grapheme from a palette of 256x256x256 colours (see Eagleman et al, 2007 for details of this interface). In this battery, the mean colour distance across the three presentations of each grapheme is converted to a standardized score, where a score less than 1 represents a distance small enough to indicate synaesthetic status (see Eagleman et al., 2007 for details). All 34 synaesthetes achieved this required score of less than one.

Results

In our analyses we compared the grapheme colours of synaesthetes with and without anxiety disorder. The output of the online testing site was the colours of graphemes encoded as RGB (red, green, blue) vector values. We first converted these values to their corresponding hue, saturation and luminance. We then averaged the luminance of all graphemes for each subject across all their responses (maximally, this was a mean across all three presentations of each letter a-z and each digit 0-9, although participants were free to omit graphemes that had no synaesthetic colour). We then repeated this for the saturation values, and finally compared both these types of means across participant groups. The

saturation of synaesthetic colours was not significantly different for synaesthetes with anxiety disorder (mean = 209.4, SD = 12.6) compared to those without (mean = 191.0, SD = 35.9; $t=1.2$, $df= 32$, $p=.2$). However, synaesthetes with anxiety disorder had significantly darker (i.e, less luminant) colours (mean = 102.3, SD = 21.5) than those without anxiety disorder (mean = 121.9, SD = 20.4; $t=-2.1$, $df= 32$, $p=.04$). This effect is illustrated in Figure 3.

Figure 3. Mean luminance of synaesthetic colours from grapheme-colour synaesthetes with and without anxiety disorder (shown as *Syn + anxiety* and *Syn - anxiety*, respectively). The lower and upper box limits first and third quartiles, and bars delimiting lowest and highest values. Outliers are shown as cases marked ‘q’.



Discussion

Our study has shown that the synaesthetic colour experiences of grapheme-colour synaesthetes are different for those with and without anxiety disorder. Those self-reporting this condition had significantly darker synaesthetic colours (i.e., lower in luminance). We discuss the implications of our findings across both studies below.

General Discussion

In our studies, we elicited synaesthetic colours for letters from groups of grapheme-colour synaesthetes, using an on-screen colour palette and converting colour selections into numeric values for hue, saturation, and luminance. In Experiment 1, synaesthetes selected their colours twice, separated by a period of several weeks, and were instructed to enter each session in a naturalistically different mood: positive on one occasion and negative on another. In each session we confirmed their mood state using the PANAS-X (Watson & Clark, 1999) and the BDI-II (Beck, Steer, & Brown, 1996) which quantify both nonclinical mood states and also depressive traits. Our questionnaire data confirmed that participants were in a significantly more positive mood when this had been requested of them. We then compared our participants' synaesthetic colours across the two (positive vs. negative) mood states in terms of changes in saturation and luminance. We found that synaesthetic colours in the negative mood state were on average significantly less luminant than in the positive mood state. A second, more speculative multiple regression analysis looked at which features of mood might influence colour changes: positive affect, negative affect (PANAS-X subscales thereof), and depressive traits (from the BDI-II scale). This analysis suggested that saturation might also be influenced by depressive traits: there was a trend towards lower saturation when depressive traits were higher. However, given that this latter trend failed to reach significance at the conventional alpha level, we will not consider it further here.

In Experiment 2 we extended this finding with another group of grapheme-colour synaesthetes. We showed that mood can alter synaesthetic colours not only when it fluctuates in non-clinical everyday life (Experiment 1), but also with it alters more dramatically, in anxiety disorder (Experiment 2). We showed that synaesthetes with self-reported anxiety disorder experience significantly darker synaesthetic colours compared to synaesthetes not suffering from anxiety disorder. Second, we addressed a methodological limitation from Experiment 1, where our request for participants to take part in a given mood state may have alerted them to the aims of our study. In Experiment 2, the aims of our study were sufficiently hidden by asking about mood (i.e., anxiety disorder) among 23 other medical conditions. In evaluating our findings, we first point out that the colour-changes that arose with mood/anxiety were not large: hence our synaesthetes were still highly consistent over time, and significantly more consistent than controls. Similarly in Experiment 1, colours for letters were overall still very similar across the two testing sessions: their mean luminance changed

by only 2 percentage points (i.e., 4.0/255) and their mean saturation by only 0.8 percentage points (i.e., 2.0/255). Hence although synaesthetic colours are influenced by mood states, they shift only marginally when mood varies within a normal (i.e., non-clinical range). Nonetheless, these differences were larger in Experiment 2, where the mood manipulation was more extreme: the colours of synaesthetes reporting anxiety disorder were more than 7 percentage points (19.6/255) darker in luminance. In both experiments, these differences were systematic and statistically significant, but the more extreme mood change caused the more extreme difference in synaesthetic colour.

We point out that our findings fit with prior literature relating mood to colour in both the general nonsynaesthetic population, and in clinical nonsynaesthetic populations. We saw above that healthy adults and children associate negative emotional moods with low saturation and luminance (Boyatzis & Varghese, 1994; Hemphill, 1996; Manav, 2007) and that depressed and anxious individuals are drawn to low saturated colours (Carruthers et al., 2010). Our own findings reflect the same direction of effects in *synaesthetic* colours. Our findings also fit with one previous study showing that an emotionally-mediated synaesthete experienced darker and less saturated colours from negatively valent words (Ward, 2004). In all cases therefore, negative mood states were linked with low luminance and/or saturation of colours. If we assume that our findings reflect similar mood changes in grapheme-colour synaesthesia, what might be at the root of these changes? One possibility is that mood may be influencing synaesthetic colours via arousal. Another possibility is that changes in synaesthetic colour by mood are mediated by attention. It is known that attention broadens in positive mood states (Compton, 2003; Wadlinger & Isaacowitz, 2006) so may indirectly influence synaesthesia simply because attention on the inducer is in some way heightened. Rich & Mattingley (2013) provide a comprehensive review of how attention influences synaesthetic colours, and one intriguing fact from our own data may speak to this issue: the PANAS has a subscale of attention (comprising the items *Alert*; *Attentive*; *Concentrating*; *Determined*). A post-hoc correlation between luminance and attention reveals a near significant r value ($r=-0.22$, $p=0.06$). This seems to suggest that one aspect of mood linked to changes in synaesthetic colour may indeed be attentiveness². Nonetheless, this result is just a trend based only on four items, and so we leave it to future studies to explore the link between attention and synaesthetic colour variation in more detail.

² We did not conduct further analyses of PANAS subscales because we had no other a priori assumptions, and therefore chose to avoid the corrections required by multiple comparisons, given also our small sample size.

We might also consider our findings in terms of the neurological bases for mood, and also for synaesthesia. Mood and emotional processing has been localised to a number of regions, most particularly the limbic system, including the hippocampus, septal nuclei, amygdala, cingulate gyrus, mammillary bodies and hypothalamus (for review see Martin, 2006). The amygdala has been particularly implicated in processing the emotional importance of stimuli, for example, in behavioural and cognitive response to stimuli that induce fear (Davis, 1992; Adolphs, Tranel, Damasio, & Damasio, 1995). However, the amygdala is also believed to be important for perception and attention (Anderson & Phelps, 2001; Williams, McGlone, Abbott, & Mattingley, 2005). For example, Young, Scannell, Burns and Blakemore (1994) found that the amygdala has connections to numerous cortical regions, including sensory regions. It is possible therefore that differences in emotional processing induced by mood changes have direct influences on visual, and other perceptual functions. Alternatively, we might consider instead one area in particular in visual cortex, V4, which has been directly implicated in synaesthetic colours (e.g., Hubbard et al., 2005), but has also been linked to the feature of contrast gain (Gardner et al., 2005). We saw above that contrast gain is altered in depressive mood states (Bubl et al., 2009; 2010). It may be possible, therefore, that the same mood-linked processes that alter contrast gain may have simultaneous effects on synaesthetic colour-selective regions in the brains of synaesthetes.

Following the completion of our own study, a related article has very recently appeared in press which is strongly compatible with our own (Dael, Sierro, & Mohr, in press). These authors, like us, have questioned the role of mood, emotion and affect in synaesthesia. Their article is an interesting opinion piece hypothesising that emotion might hold sway in synaesthesia not only as an inducer or concurrent, but also as “neither the inducer nor the direct concurrent, but a moderator or mediator of the synesthetic coupling” (Dael et al., in press). We suggest that our own study now offers precisely the data to support this speculation. Our results show empirically that mood can indeed mediate the synaesthetic experience, and we point the reader to Dael et al. (in press) for an excellent and comprehensive review of mood and emotion in both synaesthetic and non-synaesthetic perception.

In evaluating our study we would like to present two possible alternative explanations of our findings, and evaluate these alternatives in light of the data at hand. One key finding to consider when interpreting our study is that prior research has shown mood changes can

influence perception itself (e.g., Bubl et al., 2009; 2010). Given this, an alternative interpretation of our data might be that people with synaesthesia in fact have rigidly consistent synaesthetic colours, but that mood changes alter their ability to *indicate those colours* via our task. In other words, it may be that their interface with our colour wheel was compromised by changes in *real-world* perception, but their synaesthesia itself remained unchanged. A closer inspection of the direction of our data appears to speak against this possibility, and we explain this below.

Bubl et al. (2009; 2010) found that individuals with depression had lower contrast sensitivity, and although it is difficult to interpret this directly in terms of *absolute* luminance perception, it may be that this represents a shift towards under-perceiving lightness (i.e., perceiving lightness as being less light). This would certainly follow from decision studies linking negative mood states with lower luminance (e.g., Boyatzis & Varghese, 1994; Hemphill, 1996; Manav, 2007; see above). Furthermore, depressed individuals do indeed explicitly report that light appears dimmer (Friberg & Borrero, 2000), and perceptual judgements of brightness are lessened following negative (vs. positive) affect judgements (Meier, Robinson, Crawford & Ahlvers, 2007). If we extend this conclusion to the current study, we might then wish to ask whether our findings could simply be explained as our participants perceiving our screen colours as less bright when in a bad mood. If so, our findings would be unrelated to changes in synaesthesia at all. However, the direction of our findings argues against this, because we in fact found the opposite effect: selected colours were lower in luminance, but should have been higher if the screen simply appeared darker in a perceptual sense. In other words, if perception rendered the screen perceptually darker, subjects should have selected higher (not lower) levels of luminance in order to compensate. They did not: luminance fell in the negative mood state suggesting this represented an accurate selection of an altered internal colour, rather than an impaired real-world selection of an unchanged internal colour.

A second alternative interpretation of our findings is that our mood caused changes not in synaesthetic colour, but in participants' positioning of the cursor on our electronic palette. An anonymous reviewer has pointed out that luminance in both studies was manipulated vertically with lightness at the top. This leaves open the possibility that poor mood state did not affect luminance, but that instead it affected the height selected on the screen (via English spatial metaphors related to mood such as: "I feel down today"). We

investigated this possibility and found it was not the case. From the same $n=2847$ sample we examined the data of all subjects who attempted our test for synaesthesia but were ultimately not synaesthetes. Remembering that synaesthetes are those with a standardized score in our objective consistency test of <1 (see Methods), we now selected as a group of non-synaesthete controls all those who scored >2 . By coincidence, this group had the same make-up as our synaesthetes ($n=34$, of whom six had anxiety disorder). These controls completed the identical task as synaesthetes, under exactly the same testing conditions, with exactly the same instructions, and all were recruited by exactly the same method. If anxiety/ negative mood state causes people to place the cursor lower on our electronic palette we would expect again to find that those with anxiety disorder selected colours with a lower luminance. They do not: people both with and without anxiety disorder placed the cursor at the same height (i.e., they choose the same luminance) as each other. The mean luminance for those with and without anxiety disorder was 110.2 [SD= 24.0] and 107.3 [SD= 12.8] respectively ($t = 0.27$, $df=5.51$, $p=0.8$). Hence only for those with synaesthesia, does anxiety disorder lead to lower luminant (synaesthetic) colours.

In conclusion, we have found that mood states influence concurrent colours in grapheme-colour synaesthesia, and that negative states in particular give rise to colours that are lower in luminance, either as part of everyday non-clinical fluctuations in mood (Experiment 1), or as part of more extreme fluctuations of the type found in anxiety disorder (Experiment 2). We also found a trend to suggest that higher depressive traits within the non-clinical range may give rise to lower saturated synaesthetic colours. These results have implications for research into synaesthesia not only because they provide novel information about how mood alters internal perceptions, but because they challenge the traditionally held view that adult synaesthetic colours are consistent over time. We invite future researchers to explore further when and how synaesthetic colours might vary over time, as a key to better understanding the limits of this unusual condition.

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