Personality predicts the vibrancy of colour imagery: The case of synaesthesia

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Personality predicts the vibrancy of colour imagery: The case of synaesthesia

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Abstract

In this study we show that personality traits predict the physical qualities of mentally generated colours, using the case of synaesthesia. Developmental *grapheme-colour synaesthetes* have the automatic lifelong association of colours paired to letters or digits. Although these colours are internal mental constructs, they can be measured along physical dimensions such as saturation and luminance. The personality of synaesthetes can also be quantified using self-report questionnaires relating, for example, to the five major traits of Conscientiousness, Extraversion, Agreeableness, Neuroticism, and Openness to experience. In this paper, we bring together both types of quality by examining whether the personality of individual synaesthetes predicts their synaesthetic colours. Twenty grapheme-colour synaesthetes were tested with the Big Five Inventory (BFI) personality questionnaire. Their synaesthesia was also tested in terms of consistency and average colour saturation and luminance. Two major results were found: although personality did not influence the overall robustness (i.e., consistency) of synaesthesia, it predicted the nature of synaesthetes' colours: the trait of Openness was positively correlated with the saturation of synaesthetic colours. Our study provides evidence that personality and internal perception are intertwined, and suggests future avenues of research for investigating the associations between the two.

Key Words: *Grapheme-colour synaesthesia/synesthesia; Personality; Chroma; Consistency; Imagery*

1. Introduction

Our study explores the relationship between personality and colour imagery by analysing a group of individuals with a unique experience of colour. *Synaesthesia* is a well-documented condition in which sensory or cognitive modalities interact, creating unusual quasi-perceptual experiences (for review see Simner & Hubbard, 2013). For instance, reading words might trigger tastes in the mouth (Jones et al., 2011; Ward & Simner, 2003) or hearing musical sounds might induce experiences of colour in the visual field (Marks, 1975). Brain imaging studies show structural and functional differences in the brains of synaesthetes (for review, see Rouw, Scholte & Colizoli, 2011), often found in or near the sensory regions implicated in synaesthesia (e.g., V4 in colour-perceiving synaesthetes) as well as in more wide-spread regions implicated in other types of processes such as feature binding (e.g., right inferior parietal cortex; Rouw & Scholte, 2007).

This study focusses on *grapheme-colour synaesthesia* which affects between 1-2% of the population (Simner et al., 2006; Simner & Carmichael, 2015) and gives rise to unusual colour experiences triggered when the synaesthete reads or hears graphemes (i.e., letters or numbers). So reading letters and numbers, or listening to speech, or even thinking about letters and numbers triggers specific associations of colours. For example, the letter A might be, say, red for any given synaesthete, and B might be green, or the number 7 might be a particular shade of purple. Some grapheme-colour synaesthetes see their unusual colours as if they were veridical qualities in the outside in the world – for example, as colours superimposed on the written type-face when reading. Other synaesthetes see their colours as mental images in the mind's eye while others still simply have a strong sense of knowing exactly what the colours must be. These differences in the quality of the colour experience have been captured by the distinction between "projector" synaesthetes, who see colours as if they were external objects somewhere out in space, and "associators" whose synaesthetic colours are experienced only as 'knowing' or in the mind's eye (e.g., Dixon, Smilek & Merikle, 2004). Both types of grapheme-colour synaesthete show differences in white matter structure compared to controls (Rouw & Schulte, 2007), as well as functional brain markers when experiencing synaesthetic colours (see Rouw et al., 2011 for

review). The current study will examine whether these synaesthetic colours themselves are influenced by the personality profile of the synaesthete.

Pairings between graphemes and colours are largely idiosyncratic for each synaesthete but can be quantified using a *colour wheel paradigm* (e.g., Simner et al., 2006; Ward, Huckstep & Tsakanikos, 2006; Eagleman et al., 2007). In this paradigm, synaesthetes are presented with a detailed colour-palette from which they can select the exact shade of colour they perceive for any given grapheme. These choices can then be quantified, for example as values of hue, saturation and luminance, and importantly, they can be validated by the fact that colours remain highly consistent over time (e.g., Eagleman, Kagan, Nelson, Sagaram & Sarma, 2007; Simner & Carmichael, 2015). Hence a genuine synaesthete would tend to pick a similar saturation, luminance and hue for any given letter when he/she is repeatedly retested -- across weeks, months and even years (e.g., the letter A might be a very certain specific shade of red every time the synaesthete is tested). This high level of consistency can be compared with the choices of a control group, who are given instruction to *invent* consistent colours but are considerably less consistent than synaesthetes when retested. In this way, the feature of consistency is a key diagnostic metric for synaesthesia, and in our study we ask whether consistency (treated here as a marker of the 'strength' of synaesthesia) is linked to the synaesthete's personality profile.

Personality is a construct that is influenced by genetics and experiences with the environment (Bouchard, 2004; Bouchard, Lykken, McGue, Segal, & Tellegen, 1990). Understanding personality allows predictions of how someone will think, feel, and behave in response to a given situation (Passer, Smith, Holt, Bremner, Sutherland, & Vlie, 2009) and here we ask whether it can also predict a synaesthete's internal colour imagery. To measure personality traits we will use the Five Factor Model of personality (Costa & McCrae, 1992; Goldberg, 1993) which defines five domains of personality: *Openness to Experience* (a trait reflecting intellectual curiosity, imagination, and artistic interest), *Conscientiousness* (organization, self-discipline, dutifulness), *Extraversion* (gregariousness, assertiveness, sense of adventure), *Agreeableness* (compassion, helpfulness, modesty), and *Neuroticism* (anxiousness, emotional stability, impulse-control). The five-factor model has been validated cross-culturally (McCrae, 2002) and has support from neuroimaging data, since at least four of the Big Five

domains have been tied to the function and/or the structure of specific brain regions. For example, Conscientiousness is positively associated with brain volume in a region of the lateral prefrontal cortex that extends across the left middle frontal gyrus. This area is recruited during the execution of planned actions and self-regulation of behaviour, which corresponds with the description of the personality trait (DeYoung et al., 2010). To measure personality, we use the Big Five Inventory (BFI; John & Srivastava, 1999; John, Naumann, & Soto, 2008) which correlates with other the widely-used tests, including the NEO Five-Factor Inventory (NEO-FFI) and the Revised NEO Personality Inventory (NEO-PI-R) (Costa & McCrae, 1992).

There are several reasons to think that personality might be related to the strength of synaesthesia. Previous studies have concluded that synaesthetes have a distinct personality profile. For example, using the short-form NEO-PI-R (Costa & McCrae, 1992), Rouw and Scholte (2016) recently showed that individuals categorized as synaesthetes based on self-report scored higher on Openness to Experience and Neuroticism and lower on Conscientiousness, compared to a group of individuals classified as controls. Although no objective methods were used to verify synaesthesia in this study (usually an important step; see Simner et al., 2005) these findings overlap to some extent with those of Bannisy et al. (2013), whose self-referred synaesthetic sample was independently verified as genuine synaesthetes using our strength metric (i.e., consistency). Synaesthetes scored higher on Openness (as in Rouw & Scholte, 2016) and lower on Agreeableness (contrary to Rouw & Scholte, 2016) using the BFI personality questionnaire. Also in keeping with Rouw and Scholte's findings, there was a trend of higher Neuroticism in synaesthetes, but this did not reach significance after correcting for multiple comparisons. Chun and Hupé (2016) is a third study showing that (objectively confirmed) synaesthetes scored higher on Openness, as well as a related trait of absorption, an individual's' participation in and enjoyment of imaginative activities (measured using the Tellegen Absorption Scale; Tellegen & Atkinson, 1974). In summary, all three studies found evidence of higher Openness, two found a suggestion of higher neuroticism (one significantly, one at uncorrected significance only) and two studies each found one further trait: lower conscientiousness or lower agreeableness. This literature is

therefore clearly mixed, and we return to this issue in the general discussion, but we note the studies appear to converge on the finding of high openness.

Banissy et al. (2013a) proposed that synaesthetes' higher Openness may arise because their unique experience of the world predisposes them to accepting new ideas or being creative (Nelson & Rawlings, 2010; see also Rich, Bradshaw & Mattingley, 2005; Ward, Thompson-Lake, Ely & Kaminski, 2008). Banissy et al. (2013a) appeals to two possible mechanisms underlying the link between personality and subjective experience, suggesting that either the same genetic factors that influence synaesthesia also influence personality, or that synaesthesia is a causal agent of one's personality. The current study does not aim to speak to this debate, but instead examines more closely the relationship between personality and diagnosing synaesthesia: if synaesthetes tend to be high in Openness, say, and if synaesthesia is diagnosed by consistency, we might hypothesise that consistency scores may correlate with the degree of Openness. The same is possibly true of other personality traits that have (sporadically) been linked with synaesthetes (Agreeableness, Neuroticism, Conscientiousness). This proposed link between personality and consistency is the first hypothesis tested in our study.

Our second hypothesis relates to whether personality can influence the *types* of colours synaesthetes experience (e.g., how luminant or how saturated they are). Using the colour wheel paradigm, studies have shown that the mental colours of synaesthetes are influenced by several factors. Aging, for example, brings about a slight decline in the saturation of synaesthetic colours (Simner, Ipser, Smees, & Alvarez, 2017) and this has a knock-on effect for consistency because low-saturated colours are also less consistent (Simner et al., 2017). Mood too, can alter colours: Kay, Simner and Ruffell (2014) found that colours are more luminant when synaesthetes are in a positive mood (measured by the *Positive and Negative Affect Schedule*-Expanded; PANAS-X; Watson & Clark, 1999) and might be less saturated when synaesthetes are showing higher levels of non-clinical depressive traits (measured by the Beck Depression Inventory; BDI-II; Beck et al., 1996; NB non-significant trend at $p = .08$). Here we note that mood states, like depression, are generally associated with specific personality profiles (Fergusson, Horwood & Lawton, 1989; Goodwin & Friedman, 2006; Lee, 2009; Svrakic, Przybeck, & Cloninger, 1995). This link between mood and personality, and between mood and synaesthesia, raises the question

of whether the mental colours of synaesthetes are directly linked to their personality profiles. Do synaesthetes with the same personality profile share similarities in their synaesthetic colours? This is the second question we ask in our study.

Here we will test a group of grapheme-colour synaesthetes on three measures. First, we will elicit their synaesthetic grapheme-colours using the colour wheel paradigm and we will quantify those colours in terms of the linear dimensions of saturation and luminance. Second, we will objectively validate these synaesthetic colours (i.e., show they are genuine experiences of synaesthesia) by assessing their consistency over time. Third, we will evaluate synaesthetes' personality profiles using a questionnaire quantified in terms of the Big 5 personality traits. With these three types of measure (colour quality, consistency, personality) we have two predictions: that personality traits may predict the nature of synaesthetic colours in terms of their saturation/ luminance, and that they may predict the strength or robustness of the synaesthesia in terms of its consistency over time.

The direction of our predictions comes from a consideration of the literature reviewed above. Synaesthesia has been consistently linked to high Openness (Banissy et al., 2013a; Chun & Hupé, 2016; 2016; Rouw & Scholte, 2016) and has been linked in some studies to high neuroticism (Rouw & Scholte, 2016), low conscientiousness (Rouw & Scholte, 2016) and low agreeableness (Banissy et al., 2013a). We therefore predict these dimensions may correlate with the strength (i.e., consistency) of synaesthesia. Furthermore, since higher neuroticism correlates with low mood (Hepburn & Eysenk, 1989) and low mood with low saturation/luminance of synaesthetic colours (Kay et al., 2014) we predict a negative correlation between luminance and neuroticism. Finally, since synaesthesia has been linked to higher Openness (Bannisy et al., 2013; Chun and Hupé, 2016) we predict a positive correlation between openness and individual differences in synaesthesia.

2. Methods

2.1. Participants

Twenty grapheme-colour synaesthetes (13 female) were recruited from a population of synaesthetes identified in a wide-scale screening on the general population, first reported by Carmichael, Down,

Shillcock, Eagleman and Simner (2015; see also Simner & Carmichael, 2015). Our 20 synaesthetes ranged in age from 18-52 years (M = 23.27, SD = 7.40). Nine participants experienced colours for both letters and numbers, two for letters only and nine for numbers only. These 20 synaesthetes were recruited from a larger sample of 29 synaesthetes whom we targeted with invitations to take part, and these 29 were the first sub-set of synaesthetes found in the large-scale screening study conducted by Carmichael and Simner (Carmichael et al., 2015; Simner & Carmichael, 2015). The study was approved by the local university ethics committee and conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Participants received 15 pounds sterling for participation.

The authenticity of our participants' synaesthesia was determined using a behavioural 'gold standard' diagnostic as follows. As noted above, synaesthetic colour associations tend to be highly consistent over time, and synaesthetes are therefore behaviourally identified using a diagnostic test that measures this consistency (e.g., Baron-Cohen, Wyke, & Binnie, 1987; Cytowic, 1989; Ward & Simner, 2003). In our study, we employed a widely-used diagnostic test for grapheme-colour synaesthesia found at the online Synesthesia Battery (www.synesthete.org; for full methods, see Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007), which we cloned with permission of the authors (see Carmichael et al., 2015). In our test, which we will call the "*Colour Elicitation Task*" for the purposes of the current paper, participants are first asked: "Do numbers or letters cause you to have a colour experience?" Participants answered separately for whether colours were triggered by numbers (YES/NO) and letters (YES/NO), using checkboxes. Participants who indicated that they saw neither numbers nor letters in colour advanced to an exit page, whilst those who responded in the affirmative were subsequently shown a set of graphemes (letters A-Z and/or the digits 0–9, according to their responses to the questions described above). For each grapheme presented on-screen, participants selected their synaesthetic colour association from an on-screen colour palette (e.g., A=red; B=green…). Graphemes were shown three times each, in a random order, resulting in 3 colour-choices per grapheme. The distance in colour-space between these three choices forms the basis of the score in this test, with low consistency scores reflecting consistent colours (i.e., selections for the same grapheme were close in colour-space; See Eagleman et al., 2007). Genuine synaesthesia is indicated by a score less than 1 (or sometimes <1.43; see Carmichael

et al., 2015; Rothen, Seth, Witzel & Ward, 2013). All 20 participants scored below this threshold (all <1; M = 0.62, SD = 0.13) and were therefore confirmed to be genuine grapheme-colour synaesthetes. More details of the *Colour Elicitation Task* are given in our methods below.

2.2. Materials and Procedure

Participants completed two tasks: the *Colour Elicitation Task* (described in more detail below) and the Big Five Inventory (BFI) personality questionnaire (John, Naumann & Soto, 2008; see below). Participants completed the Colour Elicitation Task between September 2012 and December 2013 and were re-contacted to complete the personality questionnaire in Spring 2014. The colour elicitation task was sent as a URL link within an email invitation (see Carmichael et al., 2015; Simner & Carmichael, 2016) as was the personality questionnaire in the later email. We also gave subjects the option of completing their personality questionnaire in a word-processed document attached to the recruitment e-mail.

2.2.1. Colour Elicitation Task. Participants were shown graphemes (A-Z and/or 0-9) three times each in a random order, and instructed to select the best colour that represents their synaesthesia for each grapheme. This test diagnoses synaesthesia using a consistency measure (see 'Participants' above) while simultaneously measuring the colour values given by subjects for each grapheme in red-green-blue (RGB) colour-space (Eagleman et al., 2007). Details of the colour-palette (see Figure 1) that will be relevant to our analyses are as follows. The palette contained 16.7 million colours (256 x 256 x 256), with an option of selecting "No Colour." The colour palette showed colour graduations within a square frame, where saturation changed horizontally with high saturation to the right, and luminance changed vertically with high luminance at the top. Participants could select a colour by clicking anywhere in the frame. Hue was manipulated by a separate 'hue bar' placed vertically to the right of the palette, which could be dragged up and down using the mouse. The placement of hue from 0-360^{o} was randomly allocated on the vertical hue bar on a trial by trial basis. The colour ultimately chosen by the participant for each grapheme was displayed in a separate display below the palette, and encoded numerically in the data-stream to quantify (inter alia) its saturation and luminance. Finally, a separate horizontal bar

allowed for purely achromatic selections varying in luminance only (i.e., showing whites, greys, blacks).

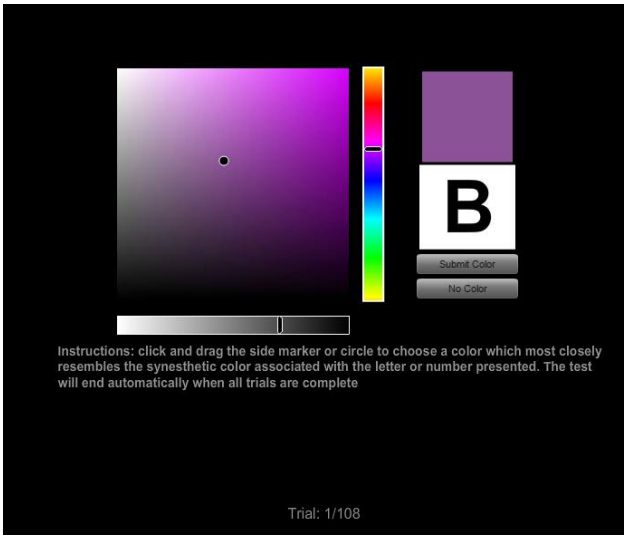

Figure 1: Example trial from the Colour Elicitation Task (Eagleman et al., 2007). Participants selected hue using the vertical 'hue bar', and desaturated colours using the horizontal bar. They adjusted chromatic saturation and luminance by clicking within the left-hand frame.

2.2.2. Big Five Inventory. Participants were asked to complete the Big Five Inventory (BFI) questionnaire, comprising 44 short descriptive phrases that capture the core elements of the five major personality factors (John, Naumann & Soto, 2008). Example items include "*I am someone who likes to spend time with others*", "*I am someone who tends to be lazy*" and *"I am someone who is helpful and unselfish with others"*. Participants are asked to rate how well they think each statement describes their own personality on a Likert scale from 1-5, where 1 indicates "Disagree strongly" and 5 indicates "Agree strongly." The BFI has high validity against the NEO-FFI and Goldberg's (1992) mini-markers, and has the benefit of being shorter, which allows efficiency and prevents participant fatigue (John et al., 2008; John & Srivastava, 1999). Finally, some participants also later completed two other self-report questionnaires, unrelated to the current study (the Interpersonal Reactivity Index and Object Spatial Imagery Questionnaire, to be reported elsewhere).

2.3. Scoring.

2.3.1. Big Five Inventory. We scored each subscale of the BFI by first reverse-scoring relevant items and then calculating the average of all responses within each subscale, per participant. In this way, each subject had a mean personality score for each of the 5 subscales (Openness, Contentiousness, Extraversion, Agreeableness, and Neuroticism).

2.3.2. Colour Elicitation Task. Each subject produced a colour consistency score, which is output automatically from our online testing resource (www.synesthete.org; see Eagleman et al., 2007). As described above, this colour consistency score is calculated by first finding the sum of the distances in normalised RGB colour-space between the three colours given for each grapheme (e.g., the sum of the distance between the three coordinates of the colours generated for the letter *A*), which is then subsequently averaged across all graphemes for that subject. We remind the reader that a small standardised score reflects consistent colours and therefore 'stronger' synaesthesia (i.e., that selections for the same grapheme were close in colour-space; See Eagleman et al., 2007 for details of this calculation). Finally, the colours selected by each synaesthete, which are initially quantified as red, green, blue (RGB) co-ordinates, were converted by us from RGB colour-space to HSL (hue, saturation, luminance) values. We then produced a mean saturation and a mean luminance per subject. Please note the same process cannot be performed on hue because this latter is a circular dimension which therefore resists linear comparisons of the type required for this study.

3. Results

In our analyses, we investigate the link between personality and synaesthesia by asking first whether personality traits are tied to the *consistency* of synaesthetes' colours, and second, whether they relate to the *quality* of their colours (i.e., the luminance and saturation). Mean consistency scores, saturation and luminance of synaesthetic colours, and personality characteristics of our sample are presented in Table 1.

Measure	Mean (SD)
Personality	
Openness to Experience	4.16 (0.66)
Conscientiousness	3.17 (0.88)
Extraversion	3.06 (0.75)
Agreeableness	3.75 (0.87)
Neuroticism	3.34 (0.94)
Synaesthesia	
Consistency	0.65 (0.18)
Saturation	71.25 (16.25)
Luminance	45.13 (9.49)

Table 1: Group Means and SDs on the Big 5 personality traits, and Consistency, Saturation and Luminance on the Colour Elicitation Task.

To further investigate our results, we also performed Bayesian analysis, the results of which we report throughout the text. First, our Bayes factors analysis allows us to evaluate to what extent the data supports the hypotheses under investigation against the null hypothesis (Rouder, Speckman, Sun, Morey & Iverson, 2009). Following Jeffreys (1961), a Bayes factor of less than 1/3 provides support for the null hypothesis, a Bayes factor larger than 3 provides support for the alternative hypothesis and values in between indicate no firm conclusions should be drawn.

3.1. Is personality linked to the quality of synaesthetic colours?

We next investigated the relationship between personality factors and the *quality* of synaesthetic colours. We examined the family of correlations between the mean saturation of synaesthetic colours for any given synaesthete, and his/her personality scores along each of the five personality dimensions. Again, we used an adjusted alpha of $p = .01$ and present uncorrected p values. There was a significant relationship between the mean saturation of colours and the personality trait of Openness, which remained significant against the corrected alpha ($r = 0.57$; $p = 0.008$; *Bayes* = 5.18). There were no other significant relationships with any other trait: Conscientiousness ($r = 0.03$; $p = 0.90$;

Bayes = 0.17); Extraversion (r = -0.09; p = 0.70; *Bayes* = 0.18); Agreeableness (r = -0.31; p = 0.18; *Bayes* = 0.41); Neuroticism (r = -0.20; p = 0.40; *Bayes* = 0.24).

Bayesian analysis for Saturation and Openness is consistent with the Frequentist analysis we performed; the Bayes Factor was greater than 3, indicating that there is evidence that two measures are indeed related. The Bayes factor for Saturation and Agreeableness was between 1/3 and 3, indicating that there is not enough evidence in the data for firm conclusions to be made. However the Bayes factors for the relationships between Saturation and Conscientiousness, Extraversion, and Neuroticism were below 1/3, indicating that there is evidence in the data in favour of the null hypothesis, or in other words that there is likely no relationship between saturation and these three personality traits.

We repeated the above analysis, this time correlating personality against mean colour luminance values, again with an adjusted alpha for the family-wise comparison. We found no significant correlations: Openness (r = -0.37; p = 0.11; *Bayes* = 0.26); Conscientiousness (r = 0.23; p = 0.33; *Bayes* = 0.72); Extraversion (r = 0.10; p = 0.66; *Bayes* = 0.19); Agreeableness (r = 0.08; p = 0.75; *Bayes* = 0.19); Neuroticism (r = -0.34; p = 0.14; *Bayes* = 0.41).

The Bayes factors for the relationships between Luminance and the traits of Agreeableness and Neuroticism were both between 1/3 and 3, indicating that there is not enough evidence in the data for firm conclusions to be made. Bayesian analysis revealed Bayes factors lower than 1/3 for the relationships between Luminance and Conscientiousness, Extraversion, and Agreeableness, indicating that there is evidence in favour of the null hypothesis.

3.2. Is personality a factor in the strength (i.e., consistency) of synaesthesia?

We first correlated the mean consistency score per subject against each of his/her Big 5 personality traits, to determine whether any trait is tied to the strength of synaesthesia (i.e., consistency). We produced five correlations, between consistency and each of the BFI traits, with an adjusted alpha level of p = .01, accordingly. There were no significant correlations between consistency and any of the personality dimensions: openness (r = 0.22; p = 0.34; *Bayes* = 0.26); conscientiousness (r = -0.39; p =

0.09; *Bayes* = 0.72); extraversion (r = -0.12; p = 0.61; *Bayes* = 0.19); agreeableness (r = -0.11; p = 0.66; *Bayes* = 0.19); neuroticism (r = 0.31; p = 0.19; *Bayes* = 0.41).

Whilst the Bayesian analysis for the relationships between Consistency and the traits of Conscientiousness and Neuroticism revealed Bayes factors between 1/3 and 3, indicating that no firm conclusions can be made, the Bayes factors for correlations between Consistency and Openness, Extraversion, and Agreeableness, were all lower than 1/3, indicating that there is evidence in favour of the null hypothesis.

4. Discussion

In this study, we investigated whether synaesthetes with similar personality profiles would also share similarities in their synaesthesia, and posed our question in two parts: Does personality influence the strength of synaesthesia (as measured by its consistency over time)? And does it influence the quality of synaesthetic colours (as measured by their saturation and luminance)?

Is personality a factor in the strength (i.e., consistency) of synaesthesia? We noted above that synaesthetes tend to be highly consistent when reporting the colours of their letters or numbers (e.g., Baron-Cohen, Burt, Smith-Laittan, Harrison & Bolton, 1996; Baron-Cohen, Wyke & Binnie, 1987; Ward & Simner, 2003) and our participants were first verified as genuine synaesthetes using the 'gold standard' consistency test (Eagleman et al., 2007). In this test, grapheme-colour synaesthetes repeatedly indicated their synaesthetic colours for graphemes, using a detailed colour-wheel, and with each grapheme presented three times. Their scores showing the average consistency of colours across the three presentations (which we take here as an indicator of the strength of synaesthesia) did not correlate with any personality traits tested. Bayesian analysis indicated that whilst no firm conclusions could be made about correlations between Consistency scores and Neuroticism and Conscientiousness, the data for Openness, Extraversion, and Agreeableness favoured the null hypothesis. We had hypothesised that the strength of synaesthesia might correlate with personality traits that have been elsewhere linked to cohorts of synaesthetes, particularly *Openness to Experience* (Banissy et al., 2013a; Chun & Hupé, 2016; Rouw & Scholte, 2016). Our logic was this: if personality predicts the condition of synaesthesia,

then the precise measure used to identify synaesthetes might itself correlate with those same personality traits. We found no evidence of this in our study. One explanation for the difference between our findings and previous ones is the distinct approach used here and in the previous studies. The current study examined relationships between variability in personality and individual differences in synaesthesia, whereas previous studies have looked at the effect of the presence (or absence) of synaesthesia on personality traits. In other words, previous studies compared personality traits of synaesthetes to those of non-synaesthetes, whereas our correlations were carried out *within* a group of synaesthetes. The absence of a linear relationship between variability in synaesthesia strength and personality traits within our group of synaesthetes does not exclude the possibility that as a group, synaesthetes – or at least those who self-referred in previous research (see below) - may differ in terms of personality from non-synaesthetes.

We also point out that the literature linking synaesthesia to personality has been somewhat mixed. Three different studies have found four different traits, three of which were found only inconsistently across labs. The only trait to be reliably found in all three studies was high Openness although we suggest that this itself may be linked to a confound in subject recruitment. We have argued previously that the self-referring synaesthete (as opposed to those identified randomly, using large-scale screening with targeted invitations and without mention of synaesthesia, as done here) might be a special type of synaesthete, unrepresentative of synaesthetes at large (e.g. Havlik, Carmichael, & Simner, 2015). Self-referred participants are individuals willing to reach out to university psychology departments to volunteer for testing or to engage in scientific research, and Dollinger and Leon (1993) have shown that such people are *a priori* high on the trait of Openness. The synaesthetes of Banissy et al. (2013a) were recruited in this type of way: via an advert specifically targeted at individuals who had previously self-referred for study given their belief they had grapheme-colour synaesthesia. In contrast, Banissy's controls were recruited differently (e.g., some were personal acquaintances who took part in response to personal request). Given these differences in recruitment, there is a risk that self-reported synaesthetes might score higher on traits such as Openness to Experience, simply by virtue of the recruitment method (i.e., because they represent the upper end of the Openness continuum in the

population at large, rather than having Openness traits tied to synaesthesia itself). So, although Banissy et al. (2013) took the important first step in asking pivotal questions about personality in synaesthesia, their recruitment methods leave areas for further examination.

Chun and Hupé (2016) claimed to have overcome the inherent biases of self-referred samples, but a close inspection of their procedure does not seem to support this claim: participants were approached at universities and museums with presentations and/or flyers describing the research project and specifically including a definition of synaesthesia. Recruited participants were those who received this information, were willing to come forward and complete an online screening questionnaire, then consented to their email being stored and then accepted an email invitation to participate. In other words, they appear to have self-referred like other self-referred synaesthesia cohorts. Rouw and Scholte (2016) in contrast had a largely unbiased method of recruitment; the authors recruited their sample via a Dutch recruitment agency as part of a larger investigation of the structural and functional correlates of individual differences, and synaesthesia was not mentioned during recruitment. Although the overall sample in this study is likely to under-represent the average person in general, this underrepresentation was, crucially, matched across synaesthete and control groups. However, synaesthesia was only self-reported, not objectively tested in their study and we have previously shown the importance of objective testing when aiming to test bona fide synaesthetes (e.g., Simner et al., 2006). In summary, the pre-existing literature on the personality of synaesthetes appears to be founded on self-referral and/or unverified synaesthesia but hints at a link with Openness to Experience.

Is personality linked to the quality of synaesthetic colours? Although personality traits were not related to the strength of synaesthesia in our study, they were related to the nature of synaesthetic colours. Synaesthetes who scored higher on Openness to Experience had synaesthetic colours that were higher in saturation. In finding a link between Openness and saturation we have shown that a personality trait tied to intellectual curiosity, imagination, and artistic interest predicts the richness of colours perceived in the mind's eye in the condition of synaesthesia. Our findings sit alongside those showing differences between synaesthetes and controls in other creative and/or colour abilities. Synaesthetes are more likely to engage in the creative arts (Rich, Bradshaw, & Mattingley, 2005; Sitton & Pierce, 2004;

Rothen & Meier, 2010; Ward et al., 2008), score higher on certain tests of creativity (Ward et al., 2008; using the *Remote Associates Test*; Mednick, 1962) and perform better than non-synaesthetes in tests of colour perception and colour memory (Banissy et al., 2013b; Banissy, Walsh & Ward, 2009; Yaro & Ward, 2007) -- although again these cohorts were self-referred. Our study adds to this body of work by also showing that traits associated with creativity have an impact on the nature of colours experienced by randomly sampled synaesthetes.

The link between Openness and saturation of synaesthetic colours may also relate to synaesthetes' abilities in mental imagery. Some studies report high levels of mental imagery in synaesthetes (Meier & Rothen, 2013; Barnett and Newell, 2008; Spiller et al., 2015; but see Havlik et al., 2015 and Chun & Hupé, 2016 for a discussion of recruitment biases) and this trait itself might relate to the saturation of colours. In other words, more saturated colours are perhaps more vivid and this could cause synaesthetes with particularly saturated colours to self-report high imagery. If so, this relationship could also mediate why those high on Openness had saturated colours, simply because vividness of visual imagery and Openness themselves inter-correlate (Chun & Hupé, 2016; Rubin & Siegler, 2004). Useful further study might pull apart the influence of imagery, saturation of colours and Openness to Experience, to dissociate the relative contributions of each.

Openness to Experience and synaesthesia may partly share underlying neural mechanisms. The personality trait has been linked – amongst other areas - to temporal and parietal activity (see Kennis, Rademaker & Geuze for a full review) and structure (Riccelli, Toschi, Nigro, Terracciano & Passamonti, 2017). Parietal cortex has increased structural connectivity in grapheme-colour synaesthetes (Rouw and Scholte (2007) and might therefore be relevant for both openness and synaesthesia; parietal cortex is recruited during the control of attention, working memory, and binding (Robertson 2003), which are processes likely to affect the flexibility with which information from different modalities can be united. Indeed, synaesthetes who are particularly high on Openness may have more saturated colours (as we have found here) because they are better able to bind, or direct attention towards their unusual sensory experience -- more so than their 'less open' counterparts. In other words, one possibility is that synaesthetes who do score higher on Openness have a more vibrant

colour experience because the trait promotes the use of areas underlying attention, binding and creative flexibility.

One might also hypothesise possible relationships between vividness, openness and parietal structure in synaesthetes since parietal cortex is recruited for cognitive control during both visual imagery and visual perception in non-synaesthetes (Ganis et al., 2004). Openness to experience also partially mediates links between creativity and increased grey matter volume in right posterior middle temporal (pMTG) gyrus in typical individuals (Li et al., 2015), an area which Rouw and Scholte reported to show greater activity in synaesthetes. Finally, right pMTG is believed to support semantic processing during novelty seeking, including generating novel connections between ideas (Binder, Desai, Graves & Conant, 2009) and language processing (Dronkers, Wilkins, Van Valin, Redfern & Jaeger, 2004), which may all be relevant for forming synaesthetic associations, perhaps in particular those that involve having linguistic inducers.

We found no evidence of links between synaesthesia and any other personality traits, including neuroticism which had been linked to synaesthesia in one previous study (Rouw & Scholte, 2016) and had been a trend in another (Banissy et al., 2013). Neuroticism also correlates with mood (Fergusson et al., 1989; Goodwin & Friedman, 2006; Lee, 2009; Mathew et al., 1979; Saklofske et al., 1995; Watson, Clark, & Carey, 1988) which has been linked to the luminance of synaesthetic colour previously (Kay et al., 2014). It is therefore surprising that we found no direct link between luminance and neuroticism here. However our Bayes analysis showed this non-significance to be inconclusive: a relationship between the neuroticism of synaesthetes and the luminance of their colours might exist, but we have insufficient evidence here, possibly due to a sample size that may be too modest for detecting a small effect size.

The purpose of the current study was to elucidate the relationship between personality and internal perception through an investigation of synaesthesia. We found no evidence that personality related to the strength of synaesthesia, but we found that Openness to Experience was significant predictor of colour saturation in synaesthesia. Our study investigated only one aspect of the relationship

between personality and internal perception. Although the link between the two has been indirectly implied by previous research in grapheme-colour synaesthetes (e.g., Kay et al., 2014) this is the first study to investigate this directly. Future studies could investigate the subtle personality and perceptual differences in other types of synaesthesia too. It is possible that synaesthetes with, for example, tactile or gustatory forms of synaesthesia might exhibit a different personality profiles and interactions.

Our results may also be applicable to the non-synaesthete population, as personality traits have been linked to visual imagery ability in the general population. For example, extroverts tend to report having vivid mental imagery more so than other personality types (Mcdougall & Pfeifer, 2012) and individuals more prone to fantasizing rated higher on Self-reported object imagery (Vannucci & Mazzoni, 2009). Jeunet et al., (2015) showed that the trait of Abstractness, measured by the 16 personality factors (16PF; Cattell & Cattell, 1995) was a significant predictor for the ability to control mental imagery-based brain computer interfaces. Abstractness is a trait related to abstract thinking and intellect, and reminiscent of the Openness to Experience trait measured in the current investigation. Future research should therefore further investigate the influence of personality on the colour qualities of internal imagery in both synaesthetes and non-synaesthetes: do all forms of mental imagery involve more saturated colours in those who are high on the personality trait of Openness? In sum, the relationship between personality traits, colour imagery, and synaesthesia lend support to the idea that imagery and personality are intricately related and that this relationship should be pursued in future studies.

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