



Are synesthetes exceptional beyond their synesthetic associations? A systematic comparison of creativity, personality, cognition, and mental imagery in synesthetes and controls

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Synesthesia has historically been linked with enhanced creativity, but this had never been demonstrated in a systematically recruited sample. The current study offers a broad examination of creativity, personality, cognition, and mental imagery in a small sample of systematically recruited synesthetes and controls ($n = 65$). Synesthetes scored higher on some measures of creativity, personality traits of absorption and openness, and cognitive abilities of verbal comprehension and mental imagery. The differences were smaller than those reported in the literature, indicating that previous studies may have overestimated group differences, perhaps due to biased recruitment procedures. Nonetheless, most of our results replicated literature findings, yielding two possibilities: (1) our study was influenced by similar biases, or (2) differences between synesthetes and controls, though modest, are robust across recruitment methods. The covariance among our measures warrants interpretation of these differences as a pattern of associations with synesthesia, leaving open the possibility that this pattern could be explained by differences on a single measured trait, or even a hidden, untested trait. More generally, this study highlights the difficulty of comparing groups of people in psychology, not to mention neuropsychology and neuroimaging studies. The requirements discussed here – systematic recruitment procedures, large battery of tests, and large cohorts – are best fulfilled through collaborative efforts and cumulative science.

Introduction

For me, numerals have colors (color glints, always the same) [. . .]. Numerals are embedded in maps [. . .]. Numerals fold and unfold, by tens, by hundreds. The maps may look different whether they refer to a number, a date, a small or a big numeral. In fact, the map is always the same but the zoom adapts. Deep within me, I have the sensation that synesthesia isolates, that it creates a distance between what I understand and what I feel. As if my ‘reading maps’ were my truth, much more dependable than utterances or words pronounced by others. In this sense, I associate synesthesia with a way of understanding things around me, but also with a type of isolation. (P.B., personal communication, 24 October 2014, translated from French).

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This elegant personal account refers to the subjective phenomenon known as synesthesia, in which specific stimulations evoke associations supplementary to what the general population experiences. These associations are arbitrary, idiosyncratic, involuntary, and automatic: they are not chosen, contrary to metaphors, are not evoked at will, and usually cannot be suppressed (for discussions on the evolving definition of synesthesia, see e.g., Hupé, Bordier, & Dojat, 2012; Simner, 2012). Synesthete P.B. experiences two common subtypes known as grapheme-colour and sequence-space synesthesia. She describes her synesthesia as a rich and complex experience including how she processes and relates to her environment. This suggests that synesthesia might be linked to other aspects of cognition and personality in addition to the production of synesthetic associations. Indeed, synesthesia has been purportedly associated with both cognitive advantages, such as superior memory, and disadvantages, such as interference with cognitive processing (e.g., Ward, 2008). It has also been suggested that synesthesia may have developed to promote the expression of creativity (Ramachandran & Hubbard, 2001). Although there is little conclusive research to date, this popular view may be strengthened by the fact that many famous artists, musicians, and authors are synesthetes (e.g., Dann, 1998; Mulvenna & Walsh, 2005). Examining the relationship between synesthesia and psychological traits could help clarify whether synesthetic associations persist in the population as part of a key developmental process. For example, it has been proposed that synesthesia may exist as a mechanism for the association of meaning (Wheeler & Cutsforth, 1922), which humans use to acquire language and represent learned associations. Below, we review the available evidence that motivated our study. When reporting results, we used the published statistics and figures to compute the confidence intervals (CI) of raw or normalized (Cohen's *d*) effect sizes (Cumming, 2012; Hupé, 2015).

In examining the relationship between synesthesia and creativity, Rich, Bradshaw, and Mattingley (2005) found that 46 of 192 self-referred synesthetes had an artistic occupation (95% CI = [18.5, 30.5]%), compared with only one out of 50 controls (2%, like in the Australian population). They were also more often actively involved in painting or drawing ([10, 31]% more than a group of 42 controls). Ward, Thompson-Lake, Ely, and Kalinski (2008) also found self-referred synesthetes ($n = 82$) to be engaged in artistic occupations at a higher rate ([12, 29]%) than expected in the UK population (7%). Additionally, they were more likely to be engaged in producing visual art ([12, 38]% more than a group of 119 controls), a result confirmed when comparing 40 synesthetes to 40 education- and occupation-matched controls. Adopting the reverse approach, Rothen and Meier (2010a) compared prevalence rates of grapheme-colour synesthesia in art students ($n = 99$) and in controls recruited from a university's anniversary event ($n = 96$), using consistency and questionnaire scores as synesthesia exclusion criteria. The authors identified seven grapheme-colour synesthetes among art students and only two among controls (difference = [-1.3, 12]%). Thus, there is some indication that synesthesia may be associated with artistic careers and hobbies; however, this does not provide evidence of whether synesthesia is directly linked with enhanced creativity.

Ward *et al.* (2008) showed that synesthetes scored higher than controls on a task measuring convergent thinking, the ability to focus and link unconnected ideas (see Table 2 for a detailed report of their results). However, a task measuring divergent thinking, the ability to solve problems by coming up with ideas, showed little group differences on the number of alternative uses generated for common objects ($d = [-0.1, 0.6]$). Notably, only the number of appropriate alternative uses was scored and *originality* of participants' responses was not assessed. The authors concluded that synesthetes may

be better at linking unrelated concepts but not necessarily at coming up with ideas. They posited that this enhanced convergent thinking may reflect the inflexible, associative nature of synesthetic experiences. The conclusions of the study were potentially limited by the recruitment methods: synesthetes were spontaneous volunteers, whereas controls were acquaintances of the research team and other participants. Furthermore, Ward *et al.* noted that creativity differences could have been due to unexamined factors such as personality traits, vocabulary, or imagery strategies. The current study aimed to overcome these limitations by examining these potentially related constructs and employing systematic recruitment.

Some researchers proposed that synesthesia may be associated with superior memory (e.g., Ward, 2008). However, demonstrations of enhanced memory are often limited to case studies and this theory has received mixed support from group studies. A review of synesthetes' mnemonic ability indicated that synesthetes only have an advantage in certain areas (Rothen, Meier, & Ward, 2012). Several studies have shown enhancements in synesthetes' ability to remember visually and auditorily presented word lists (Gross, Nearing, Caldwell-Harris, & Cronin-Golomb, 2011; Radvansky, Gibson, & McNeerney, 2011; Yaro & Ward, 2007) and word pairs (Gross *et al.*, 2011; Rothen & Meier, 2010b). For example, Yaro and Ward (2007) found that synesthetes ($n = 16$) could remember up to [0.3, 3.1] more words from a 15-word list than controls ($n = 16$) in a delayed recall phase. However, synesthetes do not seem to demonstrate enhanced memory on all tasks. For example, Rothen and Meier (2010b) measured memory performance in synesthetes recruited from a university website ($n = 44$). While the overall verbal and visual memory indices were above average (95% CI = [102, 111] and [111, 116]; norm = 100, $SD = 15$), perhaps reflecting a higher than average education level due to recruitment, performances for short-term memory tests lay within the average range, despite the use of stimuli that should evoke synesthetic associations in grapheme-colour synesthetes (see also Gross *et al.*, 2011; Rothen & Meier, 2009; Yaro & Ward, 2007). In summary, synesthetes do not have a larger memory span across the board and it is therefore possible that their enhanced recall for words could be linked to other factors, such as imagery strategies.

The most commonly accepted and reliably confirmed model of personality is the Five Factor Model, a collaborative effort of researchers over many decades. The five personality factors are openness to experience (appreciation for a variety of different experiences), conscientiousness (self-disciplined, goal-oriented tendencies), extraversion (seeking the company of others), agreeableness (compassionate and easy to get along with), and neuroticism (emotional instability, negative emotions) (Goldberg, 1999; McCrae & Costa, 1987). There is little research to date on personality traits in synesthesia. One study (Rader & Tellegen, 1987) found a positive relationship between synesthesia and absorption, or the participation in and enjoyment of imaginative activities. However, we find it problematic that many of the absorption items were directly related to or indistinguishable from synesthesia (e.g., 'Textures, such as wool, sand, wood, sometimes remind me of colours or music'), leaving unanswered the question of whether synesthetes are more prone to absorption beyond their synesthetic experiences. Another study (Banissy *et al.*, 2013) found that compared with controls, grapheme-colour synesthetes had greater openness to experience, and self-reported fantasizing – which was correlated with openness – higher neuroticism, and lower agreeableness (see Table 2 and the Discussion section for a detailed report of their results). The authors proposed that synesthesia might affect personality development. Limitations of the study include the use of only 44 items to capture the big five personality

constructs and the use of non-systematic recruitment methods. Namely, synesthetes were recruited from a database of volunteers, whereas controls were recruited from students and acquaintances.

Ward *et al.* (2008) suggested that visual imagery may be associated with both creativity and synesthesia. One study (Barnett & Newell, 2008) examined self-reported vividness of mental imagery in synesthetes recruited from national media advertisements ($n = 38$), their first-degree relatives ($n = 22$), and controls recruited from a university ($n = 38$). Synesthetes reported slightly more vivid mental imagery than controls ($d = [0, 0.9]$), with their relatives' scores intermediate to the two groups. However, sex differences were a potential confound in this study: there were 92% females (three men only) in the synesthete group versus 68% females in the control group. Females ($n = 73$) reported more vivid mental imagery than males ($n = 25$; $d = [-0.1, 0.8]$); however, the authors did not include sex in their model. Another study examined grapheme-colour synesthetes' ($n = 24$) and controls' ($n = 48$) responses on a self-report questionnaire of cognitive style, or the preference for processing information in a specific modality. Grapheme-colour synesthetes reported a greater preference for both vivid imagery ($d = [0.3, 1.4]$) and verbal style ($d = [0.1, 1.1]$) but not spatial style ($d = [-0.3, 0.7]$). Spiller, Jonas, Simner, & Jansari (2015) also reported stronger visual imagery in synesthetes (see Discussion).

In summary, synesthesia may be associated with differences in creativity, cognition, personality, and mental imagery, but these factors have not been examined simultaneously in a systematically recruited sample. In particular, when measuring personality traits, it is important to use appropriate recruitment techniques because volunteers are arguably likely to have higher openness and extraversion factor scores than people who would not spontaneously volunteer for research. Furthermore, using spontaneous volunteers excludes the population of synesthetes who are unaware of the phenomenal nature of their perceptions. It is important to note that our small sample size relative to the number of measured factors greatly limits the conclusions one can draw from our data. Nonetheless, this study offers the first exploration of creativity and its correlates in a systematically recruited sample of synesthetes and controls.

Method

Participants

Participants were systematically recruited from a large, diverse pool at universities and a scientific museum in southern France ($n = 3,743$). Initial inclusion was based on responses to an online screening survey ($n = 1,017$), where participants could indicate their email if they were potentially interested in further participation; for further details on recruitment and screening, see Chun and Hupé (2013), who published data on prevalence estimates and co-occurrence rates of synesthesia from the initial subject pool. Potential synesthetes aged 18–65 years who were right-handed and lived locally were invited to complete a survey about their synesthetic perceptions and provide a detailed list of their synesthetic associations. Synesthetes with at least 15 basic or nine complex associations (e.g., for colours: 'mauve' or 'light green') that could be tested in the laboratory were invited to participate in the study. Controls were selected using a semi-matching procedure to make the groups comparable on sex, age, education level, career/education domain, and practice of an artistic activity (the questionnaire we used is available in the Appendix of Chun & Hupé, 2013; here, we report the proportion of participants declaring a regular artistic activity leading to some production).

Synesthetes were given a surprise retest of their synesthetic associations when they came to the laboratory at least 1 week later (average delay = 26.4 days). Inclusion criteria mandated test–retest accuracy (Baron-Cohen, Wyke, & Binnie, 1987) >70% based on accuracy dispersion data from the Test of Genuineness-Revised (TOGr; Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006). Synesthetes who scored below 70% on one subtype were still included if they had other consistent subtypes. Three synesthetes were excluded due to test–retest scores <70%. The final sample of synesthetes ($n = 29$) and controls ($n = 36$) had comparable values across all demographic variables (all p 's > .35), see Table 1. These results are not necessarily representative of the populations as a whole, but reflect the overall matching of our two groups.

The final sample consisted of 22 grapheme-colour, 22 ordinal-linguistic personification, 12 sequence-colour, seven audition-colour/form, five sequence-space, five person-colour/form, four emotion-colour/form synesthetes, and one taste-colour/form synesthete (numbers add to greater than the total sample size because most synesthetes had multiple subtypes: $M = 2.7$ subtypes). See Supporting Information for the representation of subtype patterns within synesthesia. Note that the selected sample is not representative of the estimated prevalence and co-occurrence rates of synesthesia subtypes in the population (see Chun & Hupé, 2013), primarily because grapheme-colour synesthetes were preferentially recruited. This choice was motivated by the ease of the test/retest procedure. As there is no strong evidence so far that all subtypes of synesthesia share similar mechanisms (Novich, Cheng, & Eagleman, 2011) and as certain aspects of cognition and mental imagery may be associated with particular subtypes of synesthesia (e.g., Price, 2009; Simner, Mayo, & Spiller, 2009), we hoped to recruit a large enough sample of grapheme-colour synesthetes to allow for separate examinations with this more homogenous group. Despite our large initial pool, we did not recruit enough grapheme-colour synesthetes to constitute an adequate sample on their own. Results from our analyses did not appreciably change when considering grapheme-colour synesthetes alone ($n = 22$) compared with combined results for all synesthetes; therefore, analyses in this document include all synesthetes. As many of the measures in this study were created, translated, and/or culturally adapted for the first time, 11 non-synesthetes and eight self-reported synesthetes (not included in the final sample) completed pilot testing to improve the validity, clarity, and difficulty level of the measures before experimental testing began.

Procedures

Creativity and cognition tests were completed in the laboratory. A composite questionnaire examining personality traits, experiences, and activities was completed online. A complex pilot questionnaire on mental imagery was also added during the 2-year-long recruitment and testing; it was administered online. Two subjects included in

Table 1. Demographics: synesthetes ($n = 29$) versus controls ($n = 36$)

	Synesthetes, M (SD)	Controls, M (SD)
Age	23.7 (7.4)	23.1 (9.4)
Sex	61% female	66% female
Career/Education	45% science, 38% economic/social, 17% language	42% science, 39% economic/social, 19% language
Artistic activity (%)	55	56

the study did not answer our request to complete the mental imagery questionnaire. Additionally, data are missing from the personality questionnaire for one control subject and from a test of visual divergent thinking for another control subject. To ensure confidentiality of personal data and of drawings from a creativity test, a non-identifying code was used for these measures. Only the global score was linked to identifying information by the second author, who did not participate in testing and scoring. Informed, written, consent was obtained before laboratory testing, and all participants were compensated for their time.

Materials

Creativity measures

Remote Associates Test (RAT)-French Version. The original RAT (Mednick, 1967) is a measure of verbal convergent creativity, which asks participants to find the conceptual link among three words. Our version was translated and culturally adapted into French, based primarily on a 12-item version by Maddux and Galinsky (2009). Because some of the originally translated items did not transfer well culturally, several items were removed and new items were created, yielding 18 total items. The full test is available in Supporting Information. Items were presented one at a time, with 30 s per item, in an attempt to reduce differences due to timing strategies. After each failed item, participants were given the correct response to verify that they understood and did not lose motivation due to frustration.

Visual Associates Test (VAT)-French Version. The VAT is a novel test of visual, convergent creativity in which participants are asked to find the conceptual link among three images. We constructed this test based on image cards from The Best of Tribond board game (Walsh, Yearick, & Muccini, 2001, ©Tribond Enterprises) with the aim of creating a visual analog to the RAT. Some original items were used, although most were modified to ensure that the final test was culturally appropriate. See Figure 1 for an example item. The full test is available upon request from the corresponding author. Twenty items were presented for 30 s each, in the same manner as the RAT items.

Alternative Uses Test (ALT; Guilford, Christensen, Merrifield, & Wilson, 1978). The ALT assesses verbal, divergent creativity. Participants were told to provide as many uses as possible for different common objects: unique ideas that other people would not think of. Three trials were administered (brick, pencil, newspaper) with 1 min per object. Scoring was based on fluency (total number of responses), originality (one point for responses given by $\leq 5\%$ participants and two points for responses given by $\leq 1\%$ of participants), flexibility (number of different categories provided), and elaboration (amount of detail provided). Note that analyses were primarily conducted using the originality factor as it was judged to be the most important measure of everyday creativity.

Torrance Tests for Creative Thinking; Figural Test (TTCT; Torrance, 1966). The TTCT is a measure of visual, divergent creativity. Participants are asked to draw interesting stories using abstract stimuli on three tasks: (1) a dark, rounded form, (2) 10 incomplete,

QUESTION = “What do these three images have in common?”



ANSWER = *se pliant* (French)/*fold* (English)

Figure 1. Visual Associates Test (VAT) – French version, example item. Original ‘threezer’ items from the game *The Best of Tribond* are copyright protected by Tribond Enterprises. The example shown above does not contain any of the original images and has been modified to be culturally appropriate.

irregular figures, and (3) 30 pairs of straight lines. They have 10 min per task to create detailed drawings of unique ideas and add a title. The standardized TTCT scoring procedure was used to quantify the following factors: fluency (number of valid drawings), originality (non-conventionality based on standardized norms), elaboration (amount of descriptive detail), abstractness of titles, and resistance to premature closure (how much the picture diverges from the original figure). Once again, analyses were primarily conducted using the originality factor as it was judged to be the most important measure of everyday creativity.

Verbal Fluency. Participants were tested on category fluency, in which participants had 1 min to come up with as many different animals as possible (ANIMALS; Read, 1987), and letter fluency, in which participants were given 1 min to come up with as many words as possible that start with the letter C. The score for both trials was the number of categorically appropriate responses given.

Cognition measures

Wechsler Adult Intelligence Scale-Third Edition (WAIS-III; Wechsler, 1997); French version (Grégoire, 2004). The WAIS-III is a measure of global cognition standardized by age group. It has 13 subtests divided into two scales – Verbal and Performance – and four indices: Verbal Comprehension, Perceptual Organization, Working Memory, and Processing Speed.

The Association of Meaning Test (AMT). It is a novel test designed to measure associative learning. Participants were shown photographs of a body position for 4-s, followed by an abstract shape for 6-s. They had to assume and hold the position and try to memorize the associated shape (see Figure 2 for an example). Ten position–shape pairs were presented

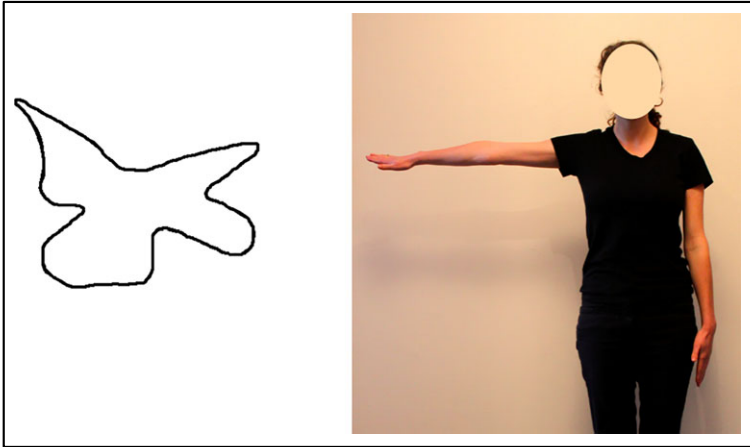


Figure 2. Association of Meaning Test (AMT) example shape–position stimulus pair.

in two learning blocks, followed by an immediate recall test and a surprise delayed recall test 1 hr 15 min later. The AMT was added during the course of the experiment so only 19 synesthetes and 26 controls were tested. We present the results of this test as exploratory.

Personality measures

OCEAN-F. The OCEAN-F is a new French translation of the 100-item International Personality Item Pool (Goldberg, 1999) based on the Five Factor Model of personality traits: openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism. Although a 60-item French Revised Version (Gibson, McKelvie, & De Man, 2008) was available, it contained many translational errors and the short version seemed unrepresentative of the big five traits. The authors, a native English speaker and a native French speaker, both fluent in both languages, created a new translation that was modified and validated during pilot testing. Our new OCEAN-F is a culturally relevant translation of all International Personality Item Pool items, with 20 items per personality trait (equal positive and negative keying) presented on a 5-point Likert scale. The full scale is available in Supporting Information.

Tellegen Absorption Scale (TAS)-French Revised Version. The original TAS (Tellegen & Atkinson, 1974) is a measure of ‘openness to absorbing and self-altering experiences’. It was composed of 34 items divided into six factors: Responsiveness to Engaging Stimuli, Synesthesia, Enhanced Cognition, Oblivious or Dissociative Involvement, Vivid Reminiscence, and Enhanced Awareness. Our new TAS-French Revised Version is a 28-item French translation with the synesthesia factor removed, presented on a 5-point Likert scale. The full scale is available in Supporting Information. Participants were instructed to describe their natural experiences only, without the influence of alcohol or other drugs.

French Questionnaire on Mental Imagery (FQMI-51). The FQMI-51 is a complex, exploratory, 51-item self-report measure of mental imagery. We decided, after pilot testing, not to use the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973)

because vividness is only one possible dimension of mental imagery. Moreover, the VVIQ requires evaluation of one's own mental vividness using an unknown standard and is therefore prone to response bias. Our 51 items explored intensity, usage, manipulation, and projection of mental imagery. The last two dimensions were particularly exploratory; therefore, this study only includes the first two subscales, which can be compared with the existing literature. Intensity items were inspired by Galton (1883), which is the original source of the VVIQ. Most items were translated and adapted citations from his original reports. Items are written from a first-person perspective, and participants are asked to rate how much their own experiences align with different proposed descriptions. For example, 'I can see my breakfast table or any equally familiar thing with my mind's eye, quite as well in all particulars as I can do if it was really before me' (ranked by Galton as number 12 of 100 reports on a scale from higher to lower intensity of visual imagery). Items are presented on a 5-point Likert scale, weighted from 1 (for *strongly agree*) to 0 (*strongly disagree*), with geometric decrease to give most weight to items subjects agree with, as they may disagree on a specific formulation for reasons other than low intensity of visual imagery. Participants were also encouraged to leave personal comments, and several subjects were interviewed. Most usage items were inspired by or translated from the Spontaneous Use of Imagery Scale (SUIS; Kosslyn, Chabris, Shephard, & Thompson, 1998) and rated in the same way.

Analyses

Primary analyses were conducted in several different steps: (1) Student's *t*-tests were used to compare synesthetes and controls on demographic characteristics, (2) descriptive statistics, coefficient alpha, and item-scale Pearson's correlations were computed to assess the psychometric properties of the two convergent creativity measures (see Supporting Information), (3) Pearson's correlations were computed among all 18 dependent measures (see Supporting Information), (4) Student's *t*-tests or analysis of variance (ANOVA) tests (see below) were used to compare all synesthetes and controls on each dependent measure, (5) Student's *t*-tests or ANOVAs were used to compare grapheme-colour synesthetes and controls on each dependent measure (data not presented in this article), and (6) follow-up analyses were conducted using Student's *t*-tests on ALT subfactors, TTCT subfactors, WAIS-III VCI tasks, and the WAIS-III digit span (see Supporting Information). We verified for all variables that the residuals were normally distributed and group variances were similar. We observed no outliers, as well as no floor or ceiling effects. We computed 95% Confidence Intervals (CI) of effect sizes when possible, using Cumming's ESCI software as needed (Cumming, 2012). We computed both raw (or normalized between 0 and 1) and standardized (Cohen's *d*) effect sizes, for both our results and those from the literature. The formula for Cohen's *d* is $d = (M_{\text{syn}} - M_{\text{con}}) / s$, with *s* being the pooled standard deviation of the two groups (Cumming, 2012). For point estimates of the population standardized effect size, we computed Hedges unbiased approximation: $d_{\text{unb}} = (1 - 3 / (4 * df - 1)) * d$.

We also used Student's *t*-tests to compare males and females on each dependent measure. Note that our recruitment strategy was aimed at matching our synesthete and control groups as closely as possible and was not targeted at matching males and females on demographic characteristics other than synesthesia. Recruitment was also performed at universities from different domains like economics, engineering, medicine, or psychology (Chun & Hupé, 2013) that have different, culturally driven sex ratios. While we matched synesthetes and controls across domains, we did not try to (and anyway could

not) match men and women on this factor. Exploring sex differences in the French population was, in any case, never the purpose of this study. However, as we had greater difficulty recruiting male volunteers and our sample was approximately 2/3 women, we chose to examine differences related to sex in our sample. Notably, females reported greater engagement in an artistic activity (76%) than males (21%; CI of difference = [30, 71]%). We also observed sex differences on several measures of creativity, personality, and cognition. These differences are much more likely to reflect recruitment bias than any real difference in the population, but we included them in the analyses to ensure that differences between synesthetes and controls could not be biased by our unbalanced sex ratio: for each dependent variable, we ran an ANOVA with group and sex as independent variables. In all cases, the interaction term was well above $p = .05$ and could be removed from the model. When the sex factor reached $p < .05$, we kept it in the model to have a better estimate of the effect size when comparing synesthetes and controls. This was the case for measures of visual convergent thinking, absorption, neuroticism, verbal comprehension, working memory, and associative learning (as denoted in Table 2). The standard deviation was also estimated based on the ANOVA model (in other words, Cohen's d was estimated based on the F value of the two-factor ANOVA instead of the Student's t -test).

Our main analysis was performed on 15 variables, which inflates the possibility of type I error over multiple comparisons. However, we did not apply any procedure for correction of multiple comparisons for two reasons. (1) This procedure is useful only when trying to reach decisions based on statistical testing. Here, we are not trying to conclude whether synesthetes and controls differ for any specific test, but are only reporting what differences were observed in our relatively small but well-matched sample. In this way, our data serve the cumulative progression of science as opposed to an independent decision (see Cumming, 2012). (2) The procedures for correcting for multiple comparisons face several problems, the first concerning definition of the family of tests. Here, we focus on 15 tests, but could have also added the four exploratory measures of mental imagery, the different indices of each test, or could have doubled the number of tests by considering sex differences. None of our differences would survive any procedure for multiple comparisons considering such a large family of tests. It has been argued that the correction for multiple comparisons is an ill-posed problem within the logic of null hypothesis significance testing (e.g., Cumming, 2012; Hupé, 2015). The second problem with some of these procedures, like the Bonferroni correction, is the assumption of independence between the multiple tests. We observed correlations among several measures in our sample, yielding such correction procedures inappropriate.

We considered several strategies to overcome the problem of multiple comparisons of correlated measures. A good strategy is to perform a principal components analysis. Although we did not have enough subjects to guarantee reliable results given the large number of variables, we tried it nonetheless, on the whole population. No large component emerged from the analysis, and no difference between controls and synesthetes was larger on any of the components than on any single measure. We then applied a second strategy appropriate for our data: a multivariate analysis of variance (MANOVA), which projects a linear combination of the measures on 'canonical variables'. The first canonical variable captures the maximum separation between groups, the second canonical variable the maximum separation while being orthogonal to the first canonical variable, and so on. The MANOVA provides one single comparison of all our data, while taking into account all correlations between variables. It captures the extent to which synesthetes differ globally from controls, by providing a statistical measure of each

canonical variable. As with factorial analysis, however, we faced the problem of dimensionality. The low number of measures may result in overfitting of the model to the data, with a resulting inflation of the significance of the observed differences. We applied two complementary methods to overcome this issue. First, we tested the susceptibility of our results to single values, by recomputing the MANOVA while systematically excluding one subject. We report the range of p -values obtained for these 63 tests.

Next, we used linear discriminant analysis with a leave-one-out procedure to determine how well a classifier trained on our data (excluding one subject) could predict whether the excluded subject is a synesthete. As with other analyses, the MANOVA and follow-up analyses were conducted using only the originality factor from the divergent thinking tasks as it was judged to be the most important measure of everyday creativity. These analyses were also conducted without mental imagery and associative learning variables, as these were exploratory measures with greater numbers of missing subjects; however, results were very similar when including mental imagery in the MANOVA.

Results

Psychometric properties of new creativity tests

Internal consistency analyses indicated a Cronbach's alpha coefficient of .45 for the VAT. The mean success rate was 0.53, which is ideal for maximizing discrimination among participants with a wide range of creative ability. Means, standard deviations, and item-scale correlations of individual items are presented in Supporting Information. Item-scale correlations measure the relation of each individual's performance on that item to their total performance, to examine how well each item measures the same overall construct.

Internal consistency analyses showed an initial Cronbach's alpha coefficient of .02 for the RAT, which is unacceptable. This was due to one problematic item for which many participants did not know the cultural reference; in these cases, we did not use the item when calculating their overall success rate. Therefore, as we only had data for 35 participants on this item and it was unassociated with the total scale, it was removed from further psychometric calculations. Group means and standard deviations did not change when including or excluding this item. Internal consistency analyses on the remaining 17 RAT items indicated a Cronbach's alpha coefficient of .37. The mean success rate was 0.50; means, standard deviations, and item-scale correlations of individual items are presented in Supporting Information.

Correlations among outcome measures

Pearson's bivariate correlations among creativity, personality, cognition, and mental imagery are shown in Supporting Information. Although modest, convergent validity was demonstrated through the correlations between the two convergent thinking measures (VAT and RAT, 95% CI for $r = [.05, .50]$), the two divergent thinking measures (TTCT and ALT, $r = [-.02, .45]$), and the two mental imagery measures (Intensity and Usage, $r = [.20, .61]$). As previously found (Phares & Chaplin, 1997), absorption correlated positively with openness to experience (TAS and O, $r = [.41, .74]$) and negatively with conscientiousness (TAS and C, $r = [-.52, -.07]$). Openness and absorption were both correlated with the usage of mental imagery ($r = [.24, .64]$ and $r = [.06, .52]$). Creativity and personality measures showed only weak intercorrelations. Largest correlation values were observed

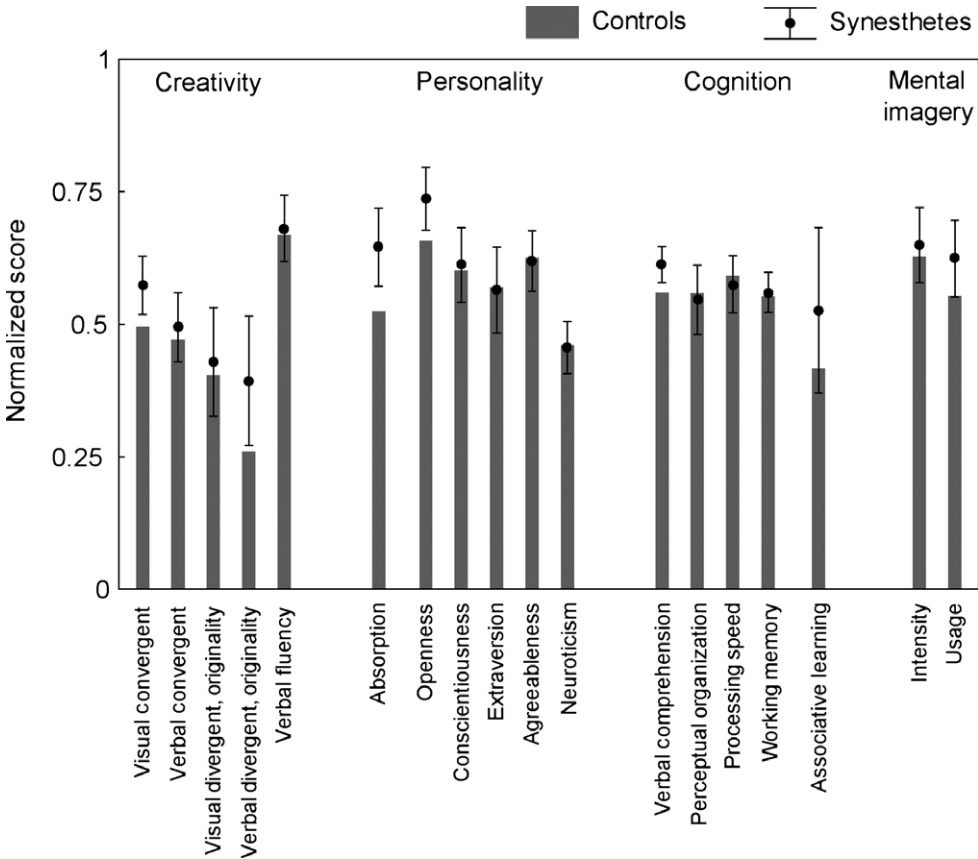


Figure 3. Comparison of all synesthetes' and controls' normalized scores on creativity, personality, cognition, and mental imagery. Normalized scores of 0 and 1 are, respectively, the min and max value for each test (see Table 2). For unbounded measures with no theoretical max values (e.g., the number of alternative uses), the max reported value in the sample was used. Shaded bars represent controls' means, and points represent synesthetes' means. Error bars represent the 95% CI for the estimation of the between-group difference (effect size relative to controls).

between neuroticism and verbal divergent thinking (N and ALT, $r = [.03, .48]$), between openness and verbal convergent thinking (O and RAT, $r = [-.08, .40]$), and between extraversion and visual convergent thinking (E and VAT, $r = [-.07, .41]$). Finally, the four cognitive indices showed sizeable intercorrelations and a number of associations with measures of creativity.

Creativity, personality, cognition, and mental imagery: Synesthetes versus controls

Normalized scores for all measures are presented for the synesthete and control groups in Figure 3. The 95% CIs estimate the between-group differences. Note that the CI for the associative learning task is much larger than the others given that fewer participants completed this task ($n = 45$). Descriptive statistics and raw effect sizes with 95% CIs are shown in Table 2 for all participants in the current study – including sample sizes for each measure to denote missing data – and in previous studies that used the same measures

Table 2. Creativity, personality, cognition, and mental imagery: All synesthetes versus controls in the current study and in previous studies (shown in italics; Banissy *et al.*, 2013; Ward *et al.*, 2008)

	[Min, Max]	<i>n</i> Syn	<i>n</i> Control	<i>M</i> Syn	<i>M</i> Control	<i>p</i>	95% CI on raw effect [low, high]
VAT ^a	[0, 1]	29	36	0.57	0.49	.006	[0.02, 0.1]
RAT	[0, 1]	29	36	0.49	0.47	.46	[-0.09, 0.04]
RAT (Ward <i>et al.</i> , 2008)	[0, 20]	76	75	13.4	11.6	.001	[0.2, 3.7]
TTCT	[0, 32]	29	35	13.8	12.9	.62	[-2.5, 4.1]
ALT	[0, 10]	29	36	3.9	2.6	.03	[0.13, 2.6]
VF	[0, 65]	29	36	44.3	43.3	.65	[-3.2, 5.0]
TAS ^a	[28, 140]	29	35	100.3	86.7	.001	[5.5, 21.9]
O	[-40, 40]	29	35	18.9	12.5	.009	[1.7, 11.2]
O (Banissy <i>et al.</i> , 2013)	[1, 5]	81	112	4.3	3.8	6E ⁻⁸	[0.3, 0.7]
C	[-40, 40]	29	35	9.0	8.0	.72	[-4.6, 6.6]
C (Banissy <i>et al.</i> , 2013)	[1, 5]	81	112	3.9	4.0	.33	[-0.2, 0.1]
E	[-40, 40]	29	35	5.2	5.5	.92	[-6.8, 6.2]
E (Banissy <i>et al.</i> , 2013)	[1, 5]	81	112	3.1	3.3	.24	[-0.4, 0.1]
A	[-40, 40]	29	35	9.6	10.0	.87	[-5.0, 4.2]
A (Banissy <i>et al.</i> , 2013)	[1, 5]	81	112	3.7	4.0	.0004	[-0.5, -0.1]
N ^a	[-40, 40]	29	35	-3.6	-3.3	.89	[-4.2, 3.7]
N (Banissy <i>et al.</i> , 2013)	[1, 5]	81	112	3.2	2.8	.01	[0.1, 0.6]
VCI ^a	[45, 155]	29	36	112.4	106.4	.002	[2.3, 9.7]
POI	[45, 155]	29	36	105.1	106.3	.73	[-8.5, 6.0]
PSI	[45, 155]	29	36	108.2	109.9	.57	[-7.6, 4.2]
WMI ^a	[45, 155]	29	36	106.7	105.6	.63	[-3.2, 5.2]
AMT ^a	[0, 20]	19	26	10.5	8.3	.16	[-0.9, 5.3]
Intensity	[-10, 10]	28	34	3.0	2.5	.51	[-0.9, 1.9]
Usage	[0, 10]	28	34	6.2	5.5	.05	[0, 1.4]

Note. Min, Max = minimum value possible to maximum value possible; Syn = synesthetes; VAT = Visual Associates Test-French Version; RAT = Remote Associates Test-French Version; TTCT = Torrance Test for Creative Thinking-Figural, Originality score; ALT = Alternative Uses Test, Originality score; VF = Verbal Fluency; TAS = Absorption, total score; O = Openness to Experience; C = Conscientiousness; E = Extraversion; A = Agreeableness; N = Neuroticism; VCI = WAIS-III Verbal Comprehension Index; POI = WAIS-III Perceptual Organization Index; PSI = WAIS-III Processing Speed Index; WMI = WAIS-III Working Memory Index; AMT = Association of Meaning Test; Intensity = FQMI-51-Intensity; Usage = FQMI-51-Usage.

^aSex included as cofactor in model.

(Banissy *et al.*, 2013; Ward *et al.*, 2008). Results are converted to standardized effect sizes (Cohen's *d*) in Figure 4. In the current study, synesthetes scored higher than controls at the level of a large effect size on absorption, (with 95% CI ranging from a small to large effect), and at the level of a medium effect size on measures of verbal comprehension (with 95% CIs ranging from a small to large effect), visual convergent thinking, verbal divergent originality, openness to experience, and usage of mental imagery (with 95% CIs ranging from negligible to large effects). Notably, the range of CIs was quite broad, indicating a lack of precision in our estimate.

Follow-up analyses on the divergent thinking subfactors, as well as specific cognitive subtests (those previously examined in the literature) for the current study and previous studies (Gross *et al.*, 2011; Rothen & Meier, 2010b), can be found in Supporting Information. Follow-up analyses on the three WAIS-III VCI subtests showed that

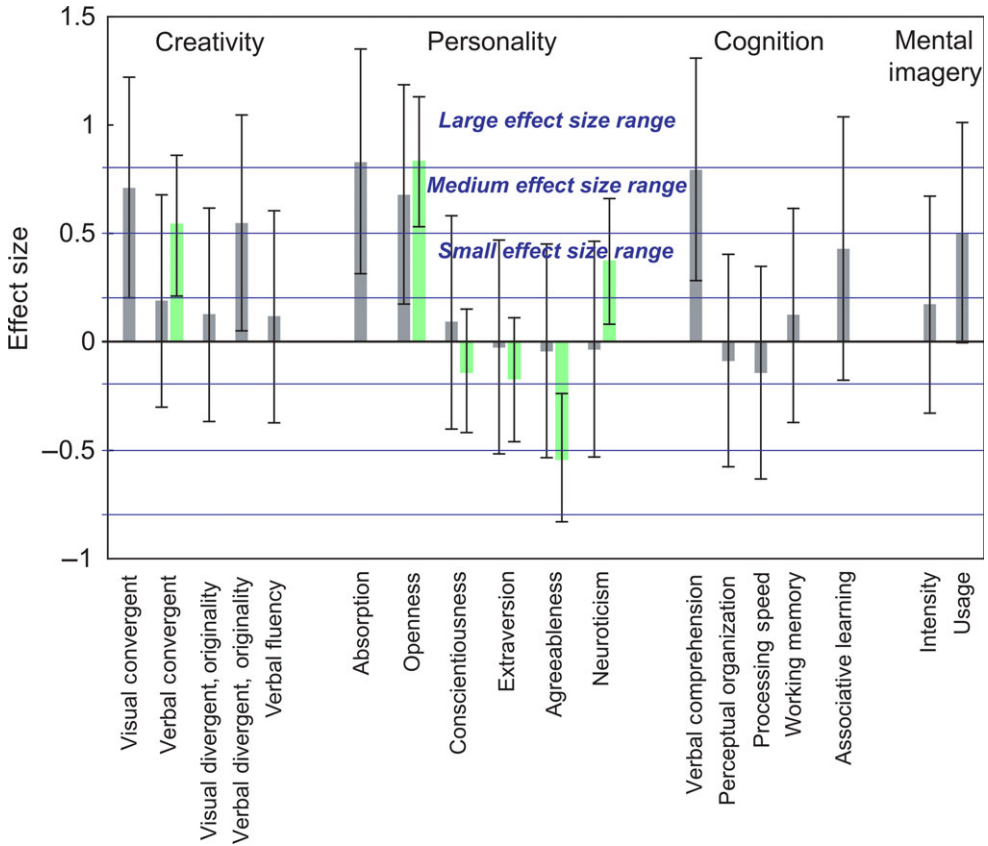


Figure 4. Standardized effect sizes of creativity, personality, cognition, and mental imagery differences between all synesthetes and controls: comparison between the current study and previous studies. Gray bars = current study. Light green bars = previous study (Banissy et al., 2013 for personality; Ward et al., 2008 for creativity). Positive values indicate that synesthetes scored higher than non-synesthetes. Negative values indicate that synesthetes scored lower than non-synesthetes. The measure of effect size is Cohen's *d*. The point estimate of the effect size is the unbiased estimate (*d* unb). Effect sizes are considered as small for $0.2 < d < 0.5$, medium for $0.5 < d < 0.8$, and large for $d > 0.8$ (Cohen, 1988). Error bars represent 95% CIs on effect sizes.

synesthetes scored higher than controls at a large effect size level for information and a medium effect size level for vocabulary (with possible effects ranging from negligible to large). The information subtest measures general knowledge across broad areas such as science, history, geography, and literature. The vocabulary subtest measures knowledge and expression of word definitions. Follow-up analyses on the WAIS-III digit span task indicated minimal group differences.

Creativity, personality, cognition, and mental imagery: Females versus males

Males were found to exceed females on verbal comprehension ($d = [0.3, 1.4]$) and working memory ($d = [0.4, 1.5]$) at the level of a large effect size and on visual convergent thinking ($d = [0.1, 1.2]$) at the level of a medium effect size. Females were found to exceed males on absorption ($d = [0.1, 1.1]$) and neuroticism ($d = [0.0, 1.1]$) at the level of a

Table 3. MANOVA results, 15 factors ($n = 63$, excluding mental imagery)

	n	Λ Wilk	F	Effect df	Error df	p	η_p^2 ^a
Group	29 syn/34 controls	.54	2.61	15	46	.0064	.46
Sex	22 men/41 women	.47	3.43	15	46	.0006	.53

Note. ^aWe conventionally report the Partial Eta square measure of effect size, but we do not think this measure is really appropriate. It probably overestimates the effect size (Cumming, 2012), and anyway seems difficult to interpret. We propose an alternative approach (see text).

medium effect size. Further analyses of verbal comprehension showed males to exceed females at a large effect size on the information subtest ($d = [0.4, 1.5]$) and a medium effect size on the vocabulary subtest ($d = [0.0, 1.0]$).

MANOVA results

MANOVA results are presented in Table 3 ($n = 63$, due to missing data on two subjects, see Procedures section). Removing the group by sex interaction ($p = .47$), we found synesthetes to differ globally from controls and men to differ globally from women when considering the 15 measures simultaneously. We verified that differences between synesthetes and controls could not be biased by the different number of men and women: when not including sex in the model, men and women did not differ on the first canonical variable that maximized the difference between synesthetes and controls ($t = 0.63$, $p = .53$). The second canonical variable did not capture any additional difference between synesthetes and controls ($p = 1$). The result did not depend on any single subject (possible overfitting issue due to the small number of subjects). When removing any one subject, p was between .0009 and .01.

To estimate the overall effect size of the difference between synesthetes and controls, we used the 15 variables to classify synesthetes and controls using linear discriminant analysis. In this way, we applied a leave-one-out procedure to evaluate the classification. When removing one subject and training the classifier on the other 62 subjects, repeated across every combination of subjects, the classifier could correctly predict whether the subject was a synesthete or a control 63.5% of the time (40/63 subjects correctly classified). Using the Binomial distribution, the 95% CI for the discriminative performance between synesthetes and controls was comprised between 50.4% and 75.3%. Assuming the Null hypothesis (chance level at 50%), this corresponds to $p = .0215$ of observing 40 or more subjects correctly classified.¹ Therefore, the MANOVA results seem valid, with possibly only slight overfitting.

Discussion

The current study examined synesthesia's associations with creativity, personality, cognition, and mental imagery using systematic recruitment and semi-matching proce-

¹ In this classification, the variable sex was ignored. As the proportion of women was almost identical in both groups (65.5% of synesthetes and 64.7% of controls), it could not be used by the classifier to distinguish synesthetes from controls. The classifiers were much better at categorizing men and women (77.8% correct [65.5, 87.3]%, $p < 6E^{-6}$ of observing 48 or more subjects correctly classified under the Null hypothesis). When including sex in the classification of synesthesia, performance was slightly better: it reached 66.7% [53.7, 78.1]%, $p = .0056$ of observing 42 or more subjects correctly classified under the Null hypothesis.

dures, to provide a more controlled examination of group differences than has previously been conducted. Because the current findings are limited by our small sample size, the 95% CIs on our effect sizes were too large to be very meaningful. However, given that our systematic recruitment spanned 1.5 years, maximizing synesthete participation from an initial pool of 3,743 people, it would require a remarkable investment of time and resources to double or triple the number of synesthetes recruited. Therefore, these findings should be viewed as a preliminary exploration of a broad number of factors, with the understanding that small sample sizes are more likely to be influenced by bias. Below, we review and interpret our findings, compare them with the literature, and discuss the broader implications of our work.

Synesthetes were shown to differ from controls on certain measures of creativity, personality, cognition, and mental imagery. Specifically, synesthetes showed (by decreasing order of estimated effect size) greater absorption, verbal comprehension, visual convergent thinking, openness to experience, originality of verbal divergent thinking, and usage of mental imagery.

Figure 4 shows standardized effect sizes of synesthetes compared with controls across all measures and in relation to the findings of previous studies for those that used the same measures (Banissy *et al.*, 2013; Ward *et al.*, 2008). CIs on the effect sizes overlapped between our study and the previous studies, meaning that results are compatible. However, the point estimates do differ notably for a few measures, in particular for openness, with a larger difference in the study by Banissy *et al.* (2013) compared with ours. These authors also found, contrary to us, that synesthetes were less agreeable and more neurotic than controls (in our data, both variables are negatively correlated). They disregarded the difference of neuroticism, considering that significance did not survive a correction for multiple comparisons.² They interpreted lower agreeableness – though unexpected – as a characteristic of synesthetes in general; however, we find it more likely that this difference (and greater neuroticism) was sample specific, perhaps due to biased recruitment. For example, they recruited controls via email from a university population and via acquaintances, whereas synesthetes were volunteers. It is logical that acquaintances who agree to come in for a study would be highly agreeable, compared with synesthetes who may have a different reason for volunteering, such as curiosity about their phenomenal condition (intellectual curiosity is one of the facets of openness to experience) or because of worrying about it (neuroticism). Although this is purely speculation, previous studies with possibly biased recruitment procedures may have overestimated effect sizes.

The current pattern of creativity findings partly corroborates those from Ward *et al.* (2008): both studies showed greater convergent thinking but in different modalities (visual vs. verbal, although only verbal was measured in Ward *et al.*, 2008). Concerning divergent thinking, neither study found group differences in fluency (the number of responses generated), but the current study extended this examination by showing that synesthetes' responses were more original. Originality reflects an important aspect of the typical view of everyday creativity but was not examined by Ward *et al.* (2008).

Regarding personality, we replicated findings of synesthetes reporting greater openness to experience (Banissy *et al.*, 2013) and absorption/fantasizing (Banissy *et al.*, 2013; Rader & Tellegen, 1987). As stated above, we did not find lower agreeableness in

² This procedure for multiple comparisons is problematic for possibly correlated variables (they used a Bonferroni correction for five tests, but their observed $p = .011$ for neuroticism does survive the False Discovery Rate procedure, which does not assume independence of tests) and when the family of possible tests is ill defined. See Method section and Hupé (2015).

synesthetes, in contrast with Banissy *et al.* (2013). Our cognitive results showed no association between synesthesia and a working memory index and, consistent with previous literature (Gross *et al.*, 2011; Rothen & Meier, 2009, 2010b), a subtest level examination revealed no group differences in memory for digits (see Supporting Information). This is corroborated by anecdotal reports from grapheme-colour synesthetes in our study, many of whom said the numbers were read too quickly (one digit per second) to attend to the synesthetic colour. However, our study did not include a comprehensive range of memory tests, such as those assessing memory for word pairs (see below for a discussion of theoretical implications), and therefore cannot be directly compared to the broader literature on memory in synesthesia reviewed by Rothen *et al.* (2012).

The current study showed synesthetes to have greater funds of general knowledge (on the information subtest) than controls and – contrary to previous studies with unverified synesthetes (Domino, 1989; Rader & Tellegen, 1987) – greater vocabulary. Taken altogether, we demonstrated some of the relationships proposed by Ward *et al.* (2008): vocabulary (a subtest of VCI) was correlated with the VAT, RAT, and ALT – but not the TTCT ($r = .10$). Mental imagery, which Ward *et al.* posited as a potential confound, was rather weakly associated with our creativity measures; however, usage of mental imagery showed a sizeable association with absorption and openness, suggesting that it has some connection with the pattern of differences expressed in synesthesia. Synesthetes reported greater use of mental imagery compared with controls, which could reflect their preference for using vivid visual imagery (Meier & Rothen, 2013). Group differences in intensity of mental imagery were, however, too small to be convincing. Barnett and Newell (2008) emphasized such a difference, but the magnitude of their reported difference was in fact at about the same level ($d = [0, 0.9]$) as ours ($d = [-0.3, 0.7]$), and may have been overestimated due to a sex bias (see Introduction). Spiller *et al.* (2015) also reported higher scores in synesthetes ($n = 103$) than in controls ($n = 102$) for both usage (SUIS, $d = [.6, 1.2]$) and intensity (VVIQ, $d = [.2, .8]$) of visual imagery; as in the other cited studies, however, the recruitment procedure was different for both groups and personality was not assessed.

Due to the covariance among measures, the observed differences in this study can be interpreted as a pattern of associations with synesthesia. To this extent, synesthetes and controls were found to differ when considering our measures as a single dimension reflecting the best summary of group differences (only one significant canonical variable in the MANOVA). Synesthetes may differ across several of the domains, but as we cannot interpret the correlations among measures, it is also possible that the pattern of differences between synesthetes and controls could be primarily explained by differences on a single measured trait – such as usage of mental imagery – or even on a hidden, untested trait. For example, we did not measure certain personality variables such as empathy (but Banissy *et al.*, 2013 did not detect group differences on this trait). This limitation applies to all other published studies that did not measure these variables simultaneously: for example, no valid conclusions can be made about differences in creativity in studies where cognition and personality were not measured.

The fact that sex differences in our study reached similar effect sizes (or larger) as differences between synesthetes and controls might suggest the need to interpret our results critically. It is quite possible that these sex differences simply reflect the unmatched nature of our male and female groups, as recruitment was not conducted with the goal of sex comparisons in mind. However, if we consider that there should not be sex

differences in the general population, this illustrates the susceptibility of small samples to spurious findings, especially when recruitment might not be strictly identical. This fact not only begs a cautious interpretation of group differences in our own small sample, it also weakens the conclusions we can draw from any study – regardless of sample size – that did not examine possible sex effects, especially as females are often recruited at a higher rate than males (e.g., Banissy *et al.*, 2013; Barnett & Newell, 2008; Ward *et al.*, 2008).

Given the possibility of bias in previous studies, it is therefore interesting that the majority of our results still replicate the extant literature. This convergence among findings yields two possible conclusions: (1) despite systematic recruitment, our study was somehow influenced by similar biases present in other studies, or (2) the differences between synesthetes and controls are robust across different recruitment methods, indicating that the observed differences may not be solely due to bias. Using the former reasoning, openness to experience seems a likely source of potential bias. Although our recruitment strategies probably increased bias towards high openness for both synesthetes and controls, synesthetes completed an additional questionnaire about their associations before being invited to participate; thus, they were likely aware of being recruited as part of a synesthete group. Therefore, synesthetes' reaction towards participating in the experiment might be more complex than controls', depending on how comfortable they are with the label of synesthesia. Indeed, many first-person reports taken from both our experience and the literature suggest that there are typically two opposing reactions people have upon discovering that they are a synesthete: the fear of being different (a weirdo or even a bit crazy), or the joy of being different (a kind of artist or someone with special powers). Thus, the final recruitment bias, if present, would be the product of complex interactions between openness and one's feelings about being a synesthete. The current study improved upon previous studies' recruitment methods by expanding our initial recruitment pool beyond spontaneously volunteered synesthetes who are, without a doubt, already aware of their synesthesia. Nonetheless, the above considerations highlight that recruitment biases were still possible in our study.

Given that our findings were robust across different analytic methods, we are confident that these results reflect real differences in our sample. However, we cannot conclude whether these differences are representative of the synesthetic population more broadly because of the large CIs and the possibility of bias. This study illustrates the difficulty of comparing groups of people in psychology, not to mention in neuropsychology and neuroimaging studies, which use very small samples and non-systematic recruitment. For example, the neuroimaging literature on synesthesia has not yet provided any evidence of neurological differences in synesthetes reproduced across studies (see Hupé & Dojat, 2015 for review); however, no study to date has controlled for factors of personality, cognition, and creativity. Whether or not the differences in these factors found in the current study are indeed systematic in synesthetes, they may at least be present in some synesthetes willing to participate in scientific research and may represent a confounding factor in many studies, thus contributing to the lack of reproducibility to an unknown degree.

What conclusions may be drawn from our data then, regarding synesthesia's implication in the development of personality and cognition: do we have evidence, as some suggest, that synesthesia produces certain cognitive advantages? The answer is not so simple when keeping in mind the bidirectional influence between individual and environment. For example, it could be that synesthesia favours the expression of one's

synesthetic experiences through artistic media (Rich *et al.*, 2005). Synesthetes' greater engagement in art and literature may foster an open-minded personality (as proposed by Ward *et al.*, 2008), stronger vocabulary, and greater tendency to fantasize, as well as more exposure to creative thinking styles. Thus, synesthesia may be *indirectly* associated with a broad pattern of cognitive factors and advantages based on the tendency to engage in certain activities and experiences (although this is, of course, just one of many possible interpretations of our data). Would this mean that training people to think like synesthetes will enhance their creativity? Not necessarily – in fact, probably not. Instead, creative thinking may be better promoted by engaging in the types of artistic hobbies and careers that synesthetes happen to select. One possible exception is convergent thinking, which restricts ideas to one 'correct' answer, in some ways the opposite of original, artistic thought. Although we did not find any benefit of short-term memory in synesthesia, the ability to think convergently and connect concepts may lead to improvements in long-term learning. This is consistent with Wheeler and Cutsforth's proposal (1922) that synesthesia may have developed as a mechanism for the association of meaning, which is present to some degree in all people and allows us to learn associations, for example, between words and concepts in language acquisition. The current study attempted to capture this ability with a novel test of associative learning that was designed to mimic a rare form of synesthesia that involves seeing colours or forms associated with body positions or movements (e.g., Mroczko-Wasowicz & Werning, 2012; Nikolic, Jürgens, Rothen, Meier, & Mroczko, 2011; note that we first assured none of our participants had this form of synesthesia). Synesthetes showed a small advantage for associative learning; however, the CIs were too large to be meaningful, likely because fewer participants completed this test. Previous studies have found enhanced memory for word pairs in synesthetes (Gross *et al.*, 2011; Rothen & Meier, 2010b). This contrast from the null findings for digit span tasks may thus be due to the associative nature of the word-pair task. In summary, we propose that observed differences in certain cognitive traits – such as divergent thinking, verbal knowledge, and personality – may be associated with an artistic lifestyle in some synesthetes, whereas theory suggests that other traits – such as convergent thinking and associative learning – may be direct correlates of synesthesia. This proposition remains to be evaluated using systematic replication.

Conclusions

The current study replicated previous findings of greater absorption, openness to experience, and convergent thinking. We also found synesthetes to have greater usage of mental imagery, verbal comprehension, and greater originality of verbal divergent thinking. We cannot yet provide any precise estimate of the magnitude of these differences; they may be minor. These differences found in our study represent a broad pattern of associations with synesthesia. Enhanced abilities in some areas of creativity, personality, cognition, and mental imagery may have developed because of experiences across time and cannot be attributed directly to synesthesia without further evidence. It is also possible that these findings only characterize those synesthetes willing to participate in (our) research and may not represent the entire synesthetic population. To understand synesthesia's neural correlates and relationships with other aspects of cognition, three components of research are required: systematic recruitment procedures, large battery of tests, and large cohorts, which are best fulfilled through collaborative efforts and cumulative science.

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Supporting Information

The following supporting information may be found in the online edition of the article:

Table S1. Subtype representation within synesthetes ($n = 29$), not representative of population prevalence and co-occurrence rates.

Table S2. Visual Associates Test (VAT)-French Version: Psychometric properties.

Table S3. Remote Associates Test (RAT)-French Revised Version: Psychometric properties.

Table S4. Pearson’s correlations among the 18 outcome measures of creativity, personality, cognition, and mental imagery.

Table S5. All synesthetes versus controls: Total and sub-factor scores of divergent creativity measures and selected WAIS-III subtests in the current study.

Data S1. OCEAN-F.

Data S2. Tellegen Absorption Scale (TAS)-French Revised Version.