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Note

# Double-blind study of visual imagery in grapheme-color synesthesia

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ABSTRACT

Synesthesia is an atypical perceptual phenomenon that has been associated with generalized differences in other cognitive and perceptual domains. Given similarities in the qualitative nature of synesthetic experiences to visual imagery perceptions, several studies have sought to examine whether synesthetes demonstrate increased visual imagery abilities. Using subjective imagery questionnaires, some studies have identified superior imaging abilities in synesthetes, while others have not. However, because most research on synesthesia uses un-blinded group membership prior to data collection, such methods for studying group differences may be prone to participant and experimenter biases (e.g., a motivated synesthete may rate themselves as having stronger visual imagery abilities due to their own bias and perceived experimenter expectations). To address this issue, we demonstrate the feasibility of double-blind designs in synesthesia research, applied here to examine differences in subjectively reported levels of imagery usage and intensity. Prior to identifying synesthetes' and non-synesthetes' group membership (in order to eliminate the potential for bias), subjects completed two common measures of visual imagery experiences. Using this approach, we replicated findings of greater visual imagery usage in synesthetes on the Spontaneous Use of Imagery Scale (SUIS) measure, but not of enhanced imagery abilities on the standardized Vividness of Visual Imagery Questionnaire (VVIQ) measure. The present study strengthens prior evidence that synesthesia is associated with heightened visual imagery and demonstrates the utility of double-blind designs in order to limit biases and promote further replicability of other findings in research on synesthesia.


## 1. Introduction

Synesthesia is the automatic and involuntary experience of one modality evoking atypical sensations in a second modality. In two of the most common forms, sounds or graphemes (letters or numbers) evoke experiences of color (sound-color and grapheme-color synesthesias, respectively; Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996; Cytowic & Eagleman, 2009). Synesthesia is present in approximately 4% of the general population, arising from a combination of hereditary and environmental factors (Asher et al., 2009; Baron-Cohen et al., 1996; Bosley & Eagleman, 2015; for a

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review see; Brang & Ramachandran, 2011; Ward & Simner, 2005).

Several competing models seek to explain how the brain gives rise to synesthetic associations. The cross-activation model proposes that altered anatomical connections between the associated modalities account for these experiences (Hubbard, Brang, & Ramachandran, 2011). For example, in grapheme-color synesthesia, neuroimaging studies have demonstrated co-activation of letter and color areas in the fusiform gyrus during passive viewing of colorless graphemes (Brang, Hubbard, Coulson, Huang, & Ramachandran, 2010; Hubbard, Piazza, Pinel, & Dehaene, 2005; Nunn et al., 2002) as well as increased anatomical connectivity between these regions (Rouw & Scholte, 2007). Conversely, the disinhibited feedback model posits that this uncommon sensory experience arises from disinhibited neural connections between various modality-specific brain regions (Grossenbacher & Lovelace, 2001). This model suggests synesthesia arises through changes in functional connectivity as opposed to anatomical connectivity, and is largely supported by studies demonstrating synesthesia induced via drugs (for reviews see Brogaard, 2013; Luke & Terhune, 2013) and sensory deprivation (Armel & Ramachandran, 1999). Additional models propose that synesthesia may not principally be a perceptual phenomenon, but rather, a conceptual phenomenon that arises from learned associations during development (Jürgens & Nikolić, 2012; Mroczko-Wąsowicz & Nikolić, 2014; Yon & Press, 2014). According to this theory, instead of being distinguished by any specific neurophysiological marker, synesthesia arises through developmental experiences resulting in cross-modal memory associations. Proponents of this theory point to the strong semantic components of synesthesia in parallel with failed replications of findings that suggest neuroanatomical differences are present in synesthetes (Dojat, Pizzagalli, & Hupé, 2018; Hupé, Bordier, & Dojat, 2011; Hupé & Dojat, 2015; Ruiz & Hupé, 2015).

The qualitative nature of synesthesia as a perceptual experience (or an exceedingly strong memory association) has drawn many researchers to question whether a link exists between synesthesia and visual imagery processes present in all individuals. Indeed, the majority of synesthetes report that they experience these sensations in their 'mind's eye,' in a similar manner to other visualized images (Barnett & Newell, 2008; Price & Pearson, 2013; Ramachandran & Hubbard, 2001). Understanding the relationship between synesthesia and more general cognitive processes like visual imagery will help clarify functional models of the phenomenon. While several studies have examined visual imagery in synesthetes relative to controls, the results remain mixed: some studies have identified enhanced visual imagery in both grapheme-color and sequence-space synesthetes (Barnett & Newell, 2008; Havlik, Carmichael, & Simner, 2015; Price, 2009; Spiller, Jonas, Simner, & Jansari, 2015; Ward et al., 2018) but these differences are not universally observed (e.g., Alvarez & Robertson, 2013, p. 317; Chun & Hupé, 2016; Spiller & Jansari, 2008; Ward et al., 2018).

Some of this ambiguity in the literature may arise from the variety of tests of visual imagery that exist, including behavioral measures of mental rotation and subjective questionnaires examining either the intensity of imagery or its usage in daily life. One reason to be cautious of the observed differences in visual imagery abilities between synesthetes and non-synesthetes assessed using behavioral surveys is that the selection processes employed in recruiting synesthetes may contaminate group differences. To our knowledge, in the majority of past studies examining this question, synesthetes are recruited to participate in research either through self-selection (synesthetes email researchers to indicate they are interested in participating) or synesthetes are identified through online or in-person advertisements. Researchers then vet synesthetes through interviews and consistency testing (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007; Hubbard & Ramachandran, 2005), including only 'verified' synesthetes who meet a sufficient number of diagnostic criteria, who may then participate in multiple studies for the same researcher. While, in principal, this common approach may be valid in many contexts, it introduces the potential for group differences in motivation, attention, and expectations about the predicted results of a study. Indeed, many individuals, upon learning they have synesthesia, become extremely motivated research participants. Participants can further introduce biases into the study by exhibiting demand characteristics—responding and acting in accordance with what they believe the experimenter wants to see (Nichols & Maner, 2008; Orne, 1959; Young, Adelstein, & Ellis, 2007). Thus, these 'verified' synesthetes may be consciously or unconsciously biased by their own predictions regarding a task within a given experiment. As such, employing these synesthetes as participants is of particular concern for studies that utilize only subjective questionnaires to compare synesthetes and non-synesthetes.

Furthermore, this recruiting and rigorous vetting process can introduce spurious effects due to experimenter expectancies, as researchers are typically aware of participants' group membership (Forster, 2000; Kennedy & Taddonio, 1976; Rosenthal, 1963; Watt & Wiseman, 2002). Experimenter expectancies can bias participants' responses and influence the outcome of the study by communicating implicit expectations to the participants either verbally or non-verbally (Adair & Epstein, 1968; Rosenthal & Fode, 1963; Rosenthal, Friedman, & Kurland, 1966). Should participants display these demand characteristics, these biases can enable a self-fulfilling prophecy in which experimenters observe from the study the results that they expected to find. In similar vein, Gheri, Chopping, and Morgan (2008) have raised their concern regarding the problematic nature of such biases in the study of synesthesia and pointed out the scarcity of efforts in the field to eliminate these confounds. At present, we are only aware of only very few studies that have taken at least a single-blind approach to studying synesthesia via self-reported measures (e.g., Ward et al., 2018). Despite the fact that these potential confounds due to sampling and experimenter/participant biases are neither new nor specific to synesthesia, these issues have not typically been flagged as serious concerns in the field.

To eliminate the potential for either experimenter or participant biases, here we applied a double-blind study design in the examination of whether grapheme-color synesthetes show increased visual imagery compared to non-synesthetes. This design required that (1) synesthetes be recruited without any explicit knowledge of the study's purpose, and (2) that the experimenters not be aware of participants' group membership. The first aim was accomplished through a pre-screening questionnaire administered to approximately 1200 undergraduates each semester at the University of Michigan. This questionnaire includes over 60 sets of questions that are pooled together across all research groups, without identifying information about specific studies or labs. Researchers then select participants based on their responses on this questionnaire, without participants being aware of the recruitment requirements for each study. After participant selection, visual imagery performance was examined using two questionnaires present in several past studies of synesthesia: the Spontaneous Use of Imagery Scale (SUIS; Kosslyn, Chabris, Shephard, & Thompson, 1998; Reisberg, Pearson, & Kosslyn, 2003), which examines the frequency in which one uses visual imagery in daily life, and the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973), which examines the intensity of such visual images. Critically, all participants were tested on these measures prior to determining their group identity. After all behavioral metrics of interest were collected, participants provided responses to standard synesthesia questionnaires and consistency testing measures to confirm synesthete and non-synesthete group membership.

## 2. Methods

### 2.1. Pre-registration

This study was pre-registered at OSF.org (https://goo.gl/kTsahV) prior to the recruitment of participants, which describes our sampling procedures, tests, and analyses procedures, independent of the data collected.

### 2.2. Pre-screening

The psychology subject pool at the University of Michigan allows pre-screening of all students currently enrolled in introductory psychology courses; this pre-screening includes around 60 questions from various labs at University of Michigan, one of which was our question regarding the experience of grapheme-color synesthesia. There was at minimum 3-week period from when the participants completed this pre-screening questionnaire to the time when they participated in this study. The exact wording of the question that was asked is provided in the Supplementary Materials (Section 1).

After completion of the pre-screening questionnaires, participants enrolled in eligible studies based on their pre-screening responses and availability; participants were neither provided information about the study nor which lab was associated with each question. Participants who provided answers 2–5 on our pre-screening question, corresponding to the answer of ‘unsure’ or ‘yes’ to experiencing color-grapheme synesthesia, were eligible for study enrollment (182 of 1280 available participants); researchers did not have access to participants' individual responses on this question. This selection process ensured a reasonable recruitment of verifiable synesthetes and non-synesthetes while maintaining blinding of participants' group membership.

### 2.3. Participants

Power analyses were conducted on the results of the SUIS scores reported by Spiller et al. (2015), indicating a Cohen's D effect size of 1.149 between synesthetes and non-synesthetes. We estimated the sample size needed a priori for a one-tailed t-test with alpha of .05 and power of .9 to be at least 14 participants in each group. Data were collected from 74 fluent English-speaking undergraduates at the University of Michigan. During analysis, participants were placed into separate groups based on their subjective reports of grapheme-color synesthesia (specifically in terms of the onset and consistency of these associations throughout their lifetime) and consistency in their grapheme-color associations (for details regarding the criterion and results of consistency test refer to Supplementary Material Section II). Specifically, we grouped participants into 4 categories: (1) Individuals not reporting any form of synesthesia (*non-synesthete controls*; $n = 45$); (2) Individuals who reported the life-long experience of grapheme-color synesthesia and who showed high consistency on a grapheme-color consistency test (*verified-synesthetes*; $n = 14$); (3) Individuals who provided ambiguous self-reports as to what they experienced (*potential-synesthetes*; $n = 11$); (4) Individuals reporting a form of synesthesia other than grapheme-color synesthesia ($n = 3$) who were excluded from all analyses. Consistency data from one verified synesthete was lost due to computer error. One additional participant was excluded for failing to follow task instructions. Out of the final 70 non-excluded participants, ages ranged from 18 to 24 (mean = 18.7, SD = 1.0) and included 50 women (See Table 1 for demographic information in each group). As confirmed with Fisher's Exact Test, a significant difference in gender was identified between the *verified-synesthetes* and the *non-synesthete controls* ($p = .044$), while no difference in gender was present for the other two comparisons (*verified-synesthetes vs potential-synesthetes*, $p = .565$; *potential-synesthetes vs non-synesthetes*, $p = .299$). To exclude the possibility that observed results were due to effects of gender, data were additionally analyzed using a restricted selection of the control subjects who were matched in gender to the *verified-synesthetes* ($N = 28$, 2 M, 26 F), with no change in results across any analysis.

### 2.4. Procedure

The structure of the experimental session was as follows: (1) Participant consenting and demographic information, (2–3)

**Table 1 – Demographics by group.**

| | Verified-synesthetes (N = 14) | Potential-synesthetes (N = 11) | Non-synesthete Controls (N = 45) |
|---|---|---|---|
| Age: M (SD) | 18.6 (1.34) | 18.4 (.50) | 18.8 (1.06) |
| Gender: | 1 M, 13 F | 2 M, 9 F | 17 M, 28 F |

VVIQ questionnaire using the original version from Marks (1973), completed with eyes open and closed, (4) SUIS questionnaire, (5) a behavioral imagery paradigm based on Thomson et al. (2008) not discussed here, (6) a debriefing question in which participants surmised the purpose of the study (no participant included descriptors of synesthesia), (7) the synesthesia questionnaire administered during pre-screening, (8) a modified variant of the projector-associator questionnaire proposed in Anderson and Ward (2015), and (9) a Java-based version of the grapheme-color consistency test (adapted from online version; Eagleman et al., 2007). Closely resembling the original (Eagleman et al., 2007), our adapted color consistency test (Supplementary Fig. S1) presented participants with an RGB color palette, allowing them to pick any color corresponding to an RGB value for a prompted grapheme. The test presented the digits 0 through 9 and all 26 letters of the English alphabet in a randomized order three different times; all 36 options appeared once before being presented again in the next randomized set, for a total of 108 trials. Excluding the consenting process, the experimental procedures and questionnaires were administered on a Windows Desktop computer.

### 2.5. *Self-report questionnaires*

The SUIS questionnaire contains 12 questions that examine the frequency of spontaneous mental imagery usage during daily life using a 5-point scale (1 = never appropriate, 5 = always completely appropriate), yielding scores ranging from 12 to 60 points. The VVIQ questionnaire contains 16 situational descriptions and instructs participants to report how vivid a given visual image is within their mind's eye using a 5-point scale (1 = perfectly clear and as vivid as normal vision, 5 = no image at all). Participants completed the VVIQ with their eyes open and then again with their eyes closed, yielding scores between 32 and 160.

### 2.6. *Data analysis*

SUIS scores were examined using unpaired *t*-tests. To identify outliers, we used the Median Absolute Deviation (scalar of 3) which is a more robust estimate of outliers than standard deviation (Leys, Ley, Klein, Bernard, & Licata, 2013). Data from one *verified-synesthete* was identified as an outlier and removed from analyses; results were unchanged by the inclusion of this subject.

VVIQ scores were reverse-coded during analysis such that higher scores reflected more vivid visual imagery. *Non-synesthete controls'* VVIQ scores were determined to be non-normally distributed according to the Shapiro–Wilks test, so VVIQ differences between the groups were first compared using the Mann–Whitney *U* test. Additionally, the square root transformation was applied to VVIQ data in order to reduce skew such that each group better approximated a normal distribution. Results were consistent with those from non-parametric analyses. Data shown in Fig. 1 (right panel) reflect non-transformed data for easier comparison with past studies of the VVIQ, whereas data in the text reflect both transformed and non-transformed data statistics. Data from one *non-synesthete control* was identified as an outlier using the Median Absolute Deviation (scalar of 3) and was removed from analyses; results were unchanged by the inclusion of this participant.

## 3. Results

*Verified-synesthetes* reported significantly greater daily usage of visual imagery [$M = 49.9$, $SD = 4.1$, 95% CI (47.5, 52.4)] compared to *non-synesthete controls* [$M = 42.2$, $SD = 5.9$, 95% CI (40.4, 43.9)], $t\,(56) = 4.42$, $p < .0001$, $d = 1.393$ (Fig. 1), as assessed through the SUIS. *Potential-synesthetes* [M = 45.5, SD = 4.0, 95% CI (42.8, 48.1)] showed an intermediary response between these two groups: *potential-synesthetes* versus *verified-synesthetes*, $t\,(22) = 2.71$, $p = .012$, $d = 1.11$; *potential-synesthetes* versus *non-synesthete controls*, $t\,(54) = 1.75$, $p = .086$, $d = .59$. Additionally, the comparison of *synesthetes* (verified and potential) versus *non-synesthete controls* further confirmed greater daily usage of visual imagery in synesthetes, $t\,(67) = 4.12$, $p < .001$, $d = 1.04$.

In contrast to the SUIS measures of visual imagery, no differences on the VVIQ measures were observed in the non-transformed data between the *verified-synesthetes* [$M = 100.9$, $SD = 34.2$, 95% CI (81.1, 120.6)] and *non-synesthete controls* [$M = 120.1$, $SD = 20.9$, 95% CI (113.8, 126.5)] ($U = 204.5$, $z = 1.87$, $p = .061$). Indeed, this result trended in the opposite direction to that of previous studies, with synesthetes showing numerically *less* vivid visual imagery than non-synesthetes (Barnett & Newell, 2008; Spiller et al., 2015). This absence of

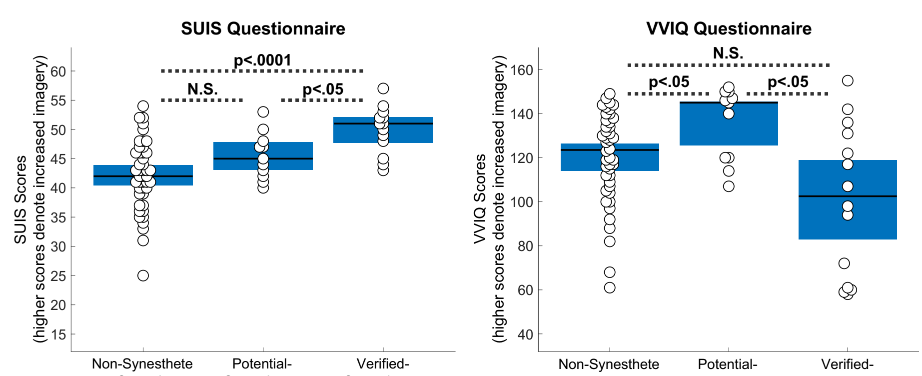


**Fig. 1 – Participant scores on SUIS and VVIQ measures of visual imagery. *Verified-synesthetes* demonstrated significantly greater imagery usage on the SUIS questionnaire, but not on VVIQ scores. Blue boxes reflect 95% confidence intervals for each group. Dark lines reflect median responses and circles reflect individual participant data points.**

more vivid visual imagery in synesthetes remained unchanged with the addition of the *potential-synesthetes* [$M = 135.5$, $SD = 16.7$, 95% CI (124.3, 146.8)] to the *verified-synesthetes*, compared to the *non-synesthete controls* ($U = 536$, $z = .17$, $p = .87$). However, one unexpected result is that *potential-synesthetes* reported greater visual imagery vividness than both *verified-synesthetes* ($U = 30.5$, $z = 2.55$, $p < .05$) and *non-synesthete controls* ($U = 124.5$, $Z = 2.47$, $p < .05$).

This pattern of results was additionally confirmed using square root transformed data along with parametric statistics. A significant difference was observed between the *verified-synesthetes* [$M = 5.35$, $SD = 2.50$, 95% CI (3.90, 6.79)] and *non-synesthete controls* [$M = 6.54$, $SD = 1.65$, 95% CI (6.05, 7.03)] on VVIQ measures, $t\,(56) = 2.09$, $p = .041$, $d = .643$. However, as in the non-transformed data, synesthetes reported *lower* visual imagery intensity scores than non-synesthetes, which is inconsistent with previous studies. This unexpected difference showed a confidence interval approaching zero [CI (.05 2.34)] and could potentially be due to the relatively small sample of synesthetes tested (such that random variability in the population does result in false positives), or be indicative of a small but genuine effect; this observation needs independent replication before further interpretations are made. We were additionally unable to detect greater visual imagery vividness in this group even after combining *potential-synesthetes* [$M = 6.50$, $SD = 2.51$, 95% CI (6.85, 9.07)] with the *verified-synesthetes*; there was no difference between this combined group and *non-synesthete controls*, $t\,(67) = .09$, $p = .940$, $d = .022$. Finally, *potential-synesthetes* again reported greater visual imagery vividness than both *verified-synesthetes*, $t\,(23) = 2.99$, $p = .007$, $d = 1.204$, and *non-synesthete controls*, $t\,(53) = 2.60$, $p = .012$, $d = .875$.

The *verified-synesthetes* group included a greater proportion of female participants than the *non-synesthete controls* group (Fisher's Exact Test, $p = .044$), introducing a potential confound to these group comparisons. Indeed, previous research has suggested that female participants demonstrate greater self-reported visual imagery (Richardson, 1995), which could explain the observed difference on the SUIS measure. To exclude this possibility, we re-analyzed these data comparing the *verified-synesthetes* (1 M, 13 F) to a proportional number of gender-matched *non-synesthete controls* (2 M, 26 F), revealing an unchanged pattern of results. On the SUIS measure, *verified-synesthetes* reported significantly greater daily usage of visual imagery [$M = 49.9$, $SD = 4.1$, 95% CI (47.5, 52.4)] compared to *non-synesthete controls* [$M = 41.6$, $SD = 5.1$, 95% CI (39.6, 43.5)], $t\,(39) = 5.20$, $p < .0001$, $d = 1.745$. On the VVIQ measure, as before, no significant difference was observed between *verified-synesthetes* [$M = 100.9$, $SD = 34.2$, 95% CI (81.1, 120.6)] and *non-synesthete controls* [$M = 120.3$, $SD = 22.1$, 95% CI (111.7, 128.8)] ($U = 129.0$, $z = 1.79$, $p = .074$). As before, this result trended in the opposite direction to that of previous studies.

## 4. Discussion

Research has demonstrated differences between synesthetes and non-synesthetes in cognitive and perceptual traits, including visual imagery (Barnett & Newell, 2008; Spiller et al., 2015), crossmodal processing (Weiss, Zilles, & Fink, 2005), memory (Rothen, Meier, & Ward, 2012; Yaro & Ward, 2007), among others. These studies largely included self-identified synesthetes for comparison against naive controls, which raises the potential for several forms of bias including, (1) motivation: synesthetes aware of their selection are more interested in the research and outcomes than naive controls, (2) expectation effects: both synesthetes' and the experimenters' beliefs of a desired outcome of the study can affect the outcome, and (3) generalization to all synesthetes: synesthetes who self-select themselves to participate in research may differ from synesthetes in general. While the design of the present study limits us from seeing how much of an effect double-blinding had on the observed survey-measures, here we demonstrate that it is possible to conduct a double-blind study on synesthesia to minimize these potential biases and replicate an established finding in the literature. Specifically, we demonstrate that grapheme-color synesthetes report greater usage of visual imagery in daily life using this double-blind procedure, demonstrating past observations of this effect were not due to differences in participants' expectation of the results or motivation, nor due to researchers' confirmation biases. However, we failed to replicate differences in the intensity of self-reported visual imagery between synesthetes and controls, indicating that this past result (Barnett & Newell, 2008; Spiller et al., 2015) may have been observed due to either confirmation or experimental biases. Indeed, in this latter study, synesthetes demonstrated significantly greater scores on the VVIQ, but this did not depend on the forms of synesthesia experienced: participants with visual synesthesias reported greater imagery intensity as did the other non-visual synesthesias examined (Spiller et al., 2015).

One possible interpretation of our findings is that in comparison to SUIS, VVIQ uses a more subjective scoring system to measure the “vividness” of an individual's visual imagery. In fact, it is likely that many individuals do not share an objective anchoring point for what mental imageries they consider to be vivid. Thus, in addition to measuring vividness of an individual's mental imagery, VVIQ may also reflect the individual's response tendencies to either under- or overestimate their self-ratings. And while we cannot make the claim that SUIS is exempt from such contamination in response tendencies, one can argue that because SUIS necessitates a more distinct, quantifiable criteria in its response selection, it serves as a relatively more objective tool for capturing the frequency of visual imagery usage. Therefore, it may be the case that color-grapheme synesthetes do indeed experience both enhanced and more frequent visual imagery but that VVIQ fails to capture this distinction.

Alternatively, another interpretation of our findings is that synesthetes do not experience enhanced visual imagery, but due to their pre-existing color and shape associations of graphemes in their “mind's eyes,” they engage in more frequent use of mental imagery. This dissociation and the interpretation is consistent with findings of Chun and Hupé (2016). In order to address the subjective nature of VVIQ, Chun and Hupé (2016) used a modified visual-imagery questionnaire (FQMI-51) that encapsulates both dimensions of imagery intensity covered in the VVIQ and usages as covered by the SUIS; even with this modified measure, they identified no difference between imagery intensity but significantly greater imagery usage in synesthetes compared to controls using a matched sample of synesthetes and non-synesthetes. Their findings, in combination with the present data, strongly suggest that synesthesia is associated with above-average use of visual imagery in daily life. The causality of this relationship, however, is yet unclear: it is possible that synesthesia arises from this excessive usage of visual imagery or that having synesthesia encourages one to use visual imagery more often. Furthermore, these data are in line with a recent study from Ward et al. (2018) who demonstrated that sequence space synesthetes reported greater usage of visual imagery compared to non-synesthetes (tested prior to the identification of synesthetes), but no differences in VVIQ scores. Ward et al. (2018) additionally reported that individuals who claimed the experience of synesthesia but who were unable to be verified as synesthetes (due to low consistency scores) reported greater visual imagery intensity than those of verifiable synesthetes. We observed a similar pattern, with *potential-synesthetes* reporting greater visual imagery intensity. Taken together, it is possible that those who experience intense visual imagery more often (falsely) report the experience of synesthesia.

The current study demonstrates that double-blind procedures are appropriate for examining differences between synesthetes and non-synesthetes in terms of broader cognitive profiles, not requiring participants' explicit usage or knowledge about synesthesia. Nevertheless, double-blind testing need not be the only method to safely control for group differences. Other groups have used large-scale sampling procedures to identify synesthetes along with different behavioral traits (e.g., Rouw & Scholte, 2016; Simner et al., 2006). A more common approach is the inclusion of various control conditions in which no difference is expected between the groups. However, this latter approach is still subject to biases by both experimenters and participants with regard to the expected outcomes of the study. The simple procedure applied here protects the research hypotheses from unintentional contamination by either participants or researchers during data acquisition or analysis. In summary, this approach can supplement these other methods in replicating findings in synesthetes to ensure generalizability of the results. The current approach could be expanded to studies that make use of the participants' specific synesthetic associations within the task of interest by requesting those associations during the initial pre-screening procedure, making it possible to generalize this method to all studies in the field of synesthesia.

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## Supplementary data

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