# Do sequence-space synaesthetes have better spatial imagery skills? Yes, but there are individual differences

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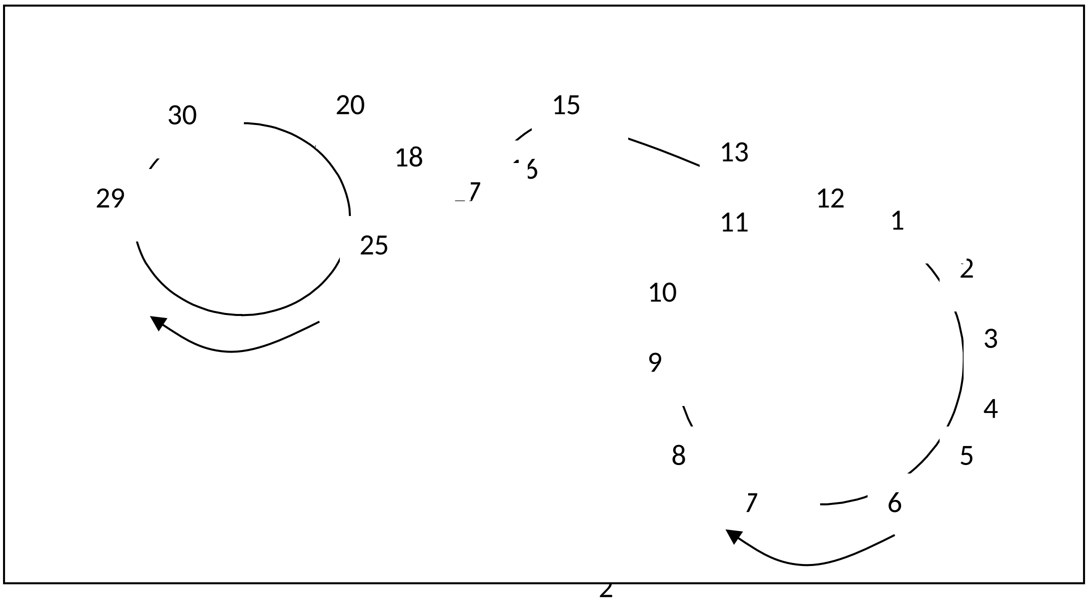
**Abstract**

People with *sequence-space synaesthesia* perceive sequences (e.g., numbers, months, letters) as spatially extended forms. Here we ask whether sequence-space synaesthetes have advantages in visuo-spatial skills such as mental rotation. Previous studies addressing this question have produced mixed results with some showing mental rotation advantages (Simner, Mayo & Spiller, 2009; Brang, Miller, McQuire, Ramachandran & Coulson, 2013) but one that did not (Rizza & Price, 2012). We tested this hypothesis again with a new group of sequence-space synaesthetes, and we also tested a range of individual differences that might have caused this conflict across previous studies. Specifically we tested: years of education, visual imagery ability, nature of forms (2D or 3D representation of sequences), number of forms (e.g., for months, days, numbers), and tendency to project sequences into external space versus the mind's eye. We found yet again that synaesthetes had enhanced abilities in mental rotation compared to controls, but that one individual difference in synaesthetes (the ability to project forms into space) was especially linked to performance. We also found that synaesthetes self-reported higher visual imagery than controls (Price, 2009; Mann, Korzenko, Carriere, & Dixon, 2009; Rizza & Price, 2012). Overall, our data support previous studies showing superior imagery reports (Price, 2009) and mental rotation (Simner et al., 2009; Brang et al., 2013) in sequence-space synaesthetes, and we suggest that one previous failure to replicate (Rizza & Price, 2012) might be explained by individual differences among synaesthetes recruited for testing.

## Introduction

Synaesthesia is a condition with a neurological basis (e.g., Hubbard & Ramachandran, 2005) and likely genetic roots (e.g., Asher et al., 2009) which gives rise to usual secondary sensations. For example, synaesthetes might experience colours when hearing music, or they might taste flavours when reading words (see Simner & Hubbard, 2013 for review). The current study examines one variant in particular: *sequence-space synaesthesia* in which sequences such as months of the year, days of the week, numbers, letters, etc. are experienced as specific *forms* in space (e.g., Simner, 2009). For example, Figure 1 shows the spatial form of synaesthete JC, for the sequence of days within a month. Estimates of the prevalence of sequence-space synaesthesia have varied in the contemporary literature from 2.2% of the population (Brang, Teuscher, Ramachandran & Coulson, 2010) to 12% (Tang, Ward and Butterworth, 2008), to 17% (Rizza & Price, 2012), to as much as 29% (Sagiv, Simner, Collins, Butterworth & Ward. 2006). Our aim is to examine whether individuals with sequence-space synaesthesia show cognitive advantages when compared to the general population, and whether there are individual differences among sequence-space synaesthetes that might moderate these advantages.

*Figure 1:* Example of a synaesthetic sequence-space form (for days within a month), experienced by synaesthete participant JC; from Simner, Mayo and Spiller (2009).



Sequence-space synaesthetes often claim to be able to manipulate the viewing-angle and/or size of their synaesthetic forms by taking multiple perspectives, or mentally re-orienting the array, or by ‘zooming in’ on certain portions (e.g., Simner et al., 2009; Jarick et al., 2009, Eagleman, 2009). Consequently, these individuals might be considered relatively well practised in manipulating mental objects and could therefore perhaps perform well in similar visuo-spatial tasks conducted in the lab. Indeed, Simner et al. (2009) found that sequence-space synaesthetes outperformed controls on a variety of tasks linked to visual and/or spatial imagery/memory, including the *California Test of Mental Rotation* (Cherry et al., 2007). Their small group of n=5 synaesthetes scored significantly more accurately in mental rotation than controls. A subsequent study however (Rizza and Price, 2012) failed to replicate this effect with n=9 synaesthetes using rotation stimuli from Shepard and Metzler (1971), and concluded that “demand characteristics may have contaminated group comparisons based on small samples of synaesthetes [in Simner et al., 2009].” (Rizza and Price, 2012; pg. S302). Nonetheless, a more recent study (Brang et al., 2013) subsequently did replicate this effect, by showing that n=15 sequence-space synaesthetes scored significantly more accurately than controls on their own rotation task (for the mental rotation of letters). In the current paper we provide yet another behavioural replication of the advantage of sequence-space synaesthetes in mental rotation, as well as an attempt to understand why Rizza and Price failed to find the effect in their own paper. In particular, we look here at the question of individual differences among synaesthetes, and whether this might explain why one test of mental rotation in four did not show the effect in question. The individual differences we test in the current study relate to: number of synaesthetic forms (e.g., for days, numbers, months etc.), whether forms occupy two dimensional (2D) space or three dimensional (3D) space, whether they are projected outside the body (vs. within the mind's eye), the synaesthete's number of years of education, and their visual imagery ability in self-report. We consider these differences in turn below, and discuss how each might influence synaesthetes' performances in mental rotation tasks.

*Individual Differences in Synaesthetes*

Although some traits are shared across sequence-space synaesthetes (e.g., the fact that forms tends to remain consistent over time; e.g., Sagiv et al., 2006), there are other aspects of sequence-space synaesthesia that vary from synaesthete to synaesthete. One obvious difference is that some synaesthetes experience only very few forms, while others experience many. For example, synaesthete L. experiences three forms, for numbers, months of the year and hours in the day (Jarick, Dixon, Stewart, Maxwell & Smilek, 2009) while synaesthete DG has at least 58 different forms, including forms for height, TV stations, body temperature, and even pure-bred dog naming sequences (Hubbard, Ranzini, Piazza and Dehaene, 2009). Hence synaesthetes differ in terms of the number of forms they experience. It is interesting to note that the synaesthetes tested in Rizza and Price (2012) – where no mental rotation advantage was found -- were only required to have spatial forms for "at least 2 types of sequence" (Rizza and Price, 2012; pg. S300) while those in Simner et al. (2009) – where mental rotation was superior -- had an minimum of four. This raises the possibility that synaesthetes who perform well in mental rotation might be those with a greater number of forms.

Synaesthetes can also differ in the way their forms are experienced: firstly, forms can occupy either 2D space or 3D space (Brang et al., 2013). A 3D form might extend away from the body horizontally, vertically and laterally, while 2D forms might extend, for example, just in a planar circle. Price (2013) suggests that 3D synaesthetes may reside on the upper end of a visual imagery spectrum compared to those with 2D forms although very little is known about how or why forms vary in their dimensionality, and what impact this might have on related abilities. Synaesthetes' forms can also be diverse in other ways too. 'Projector' sequence-space synaesthetes see their form occupying physical space outside the body (Dixon, Smilek & Merikle, 2004). In contrast 'associator' synaesthetes simply visualise their forms in some kind of internal mental space, often described as being 'within the mind's eye'. Associators also include synaesthetes whose spatial forms are 'known but not seen' (Ward, Salih, & Sagiv, 2007); i.e., they are experienced in some abstract sense but not seen in any type of (internal or external) imagery at all. Here we ask whether these two types of features (2D/3D; projector/associator) might also influence mental rotation skills. For example, it is possible that *projected* forms in particular – i.e., those with object-like qualities that are imaged outside the body -- could perhaps be somehow more tangible and so more easily manipulated; if so, projector synaesthetes might be more practiced in mental rotation type tasks. Equally, performance on a mental rotation task might be enhanced if the rotation task is congruent to the synaesthetic spatial representation: 3D spatial forms might benefit a 3D mental rotation task (see Brang et al., 2013 for a similar argument[1]). For both these reasons, we also include these two individual differences in our study and ask how they might predict performance on tests of mental rotation.

A fourth individual difference across sequence-space synaesthetes is naturally occurring fluctuations in education or IQ. One study showing an advantage for synaesthetes (Simner et al., 2009) just happened to have tested particularly highly educated synaesthetes: 60% had postgraduate degrees. It is already known that levels of intelligence positively

1 There is no evidence of systematic difference across previous studies in the presence of 2D/3D forms, and the use of 2D/3D rotation tasks: Simner et al. (2009) and Rizza and Price (2012) both used a 3D object rotation task whereas Brang et al. (2013) used a 2D grapheme rotation. No information regarding spatial dimensionality of forms was reported in either Simner et al. (2009) or Rizza and Price (2012), although Brang and colleagues concluded that within their sample of synaesthetes (N=117), there was nearly a 50:50 split between those that experienced their forms as 2D or 3D.

correlate with performance on tests of spatial ability (Hegarty & Kozhevnikov, 1999) and for this reason, the synaesthetes tested by Simner et al. (2009) were carefully matched to controls in IQ. Despite this matching however, it is possible that synaesthesia may *interact* with intelligence to allow synaesthetes with higher IQ to somehow profit more from their forms (e.g., they may inspect and/or manipulate them more often, or may better profit from them strategically in tasks). In other words, it is still possible that synaesthetes with higher IQs may perform better than those with lower IQ, compared to their relative matched controls. Considering this, we will also assess here the impact of IQ on synaesthetes' mental rotation, and we will test IQ by proxy in terms of year of education.

One final individual difference that may influence synaesthetes' performance in mental rotation is *a priori* mental imagery ability. Mental rotation is enhanced by strong visual imagery: Weatherly (1997) for example reported that high visual imagers perform particularly well in tasks of mental rotation. Additionally, Logie, Pernet, Buonocorea and Della Sala (2011) showed that individuals self-reporting high visual imagery (using the Vividness of Visual Imagery Questionnaire; VVIQ; Marks, 1973) were more accurate at a mental rotation task than those self-reported as low imagers. Logie, Weatherly and colleagues argue that high imagers may use more successful task-completion strategies whereas low imagers may rely on techniques more predisposed to errors.

Here we have reviewed five types of individual differences among sequence-space synaesthetes. Collectively, these five types of individual differences among sequence-space synaesthetes could, in theory, impact their performance in mental rotation tasks. The issue for the current paper then is whether these individual differences might influence performance in mental rotation, and indeed whether synaesthetes overall perform mental rotation better than controls. To this end we present the empirical study below. Following our previous work (Simner et al., 2009; also Brang et al., 2013) we hypothesise that sequence-space synaesthetes will out-perform controls in mental rotation. We also hypothesise that performance may be better in those with a greater number of forms, and/or those who are projectors (vs. associators), and/or those with 3D forms (vs. 2D, since we are using a 3D task), and/or those with high visual imagery ability and/or a higher IQ. These differences, individually or in combination with each other, could represent differences in the "strength" of the synaesthetic experience. In line with previous research (see Price, 2009; Mann et al., 2009), it is also expected that synaesthetes will self-report a higher level of visual imagery compared to controls.

To add weight to our earlier findings (Simner et al., 2009) the current study uses a larger sample of synaesthetes to overcome the possibility of type II errors. We also took care to have subjects interact with a new experimenter in case our earlier findings had been influenced in any way by unconscious experimenter bias (Author AMH interacted with participants here, while JS interacted with participants in Simner et al., 2009). Finally, we chose precisely the mental rotation task employed by Rizza and Price (2012; see below) to ensure that our methods were closely comparable with the one study that failed to show our effect previously.

## Experiment

### Methods

#### Participants

We tested 30 participants: 15 sequence-space synaesthetes and 15 control non-synaesthetes. Synaesthetes were matched group-wise to controls for sex (12 females per group) and years of education (synaesthetes: *M* = 16.7, *SD* = 2.7; controls: *M* = 16.0, *SD* =

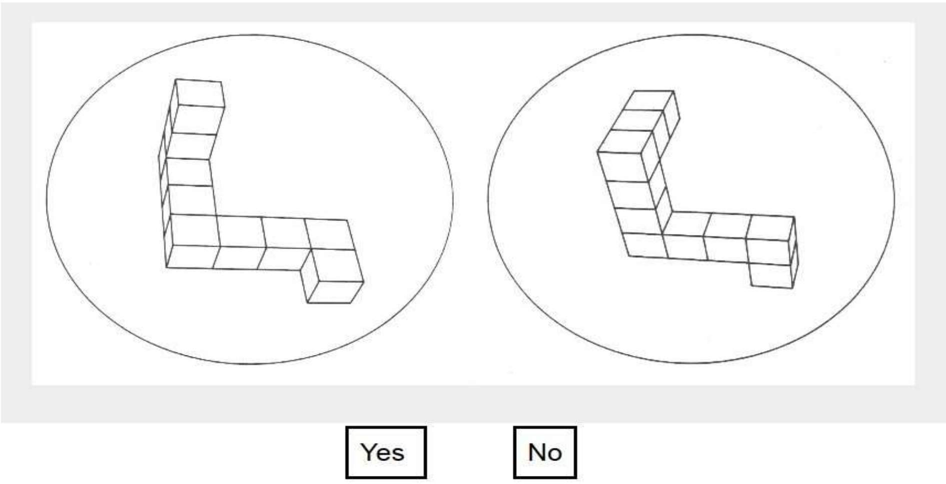
2.5). The mean age of synaesthetes was 35.4 years (*SD* = 13.4) and the mean age of controls was 33.8 years (*SD* = 11.9). Synaesthetes were recruited from a database of self-referred synaesthete participants and from an online discussion forum for synaesthetes (Day, 2013). Synaesthetes were verified by their responses to a written questionnaire in which they reported a spatial layout to sequences such as days, months, letters etc. In the course of our study (see below) they also gave detailed information about the number and nature of their forms (e.g., 2D/3D layout; projected/associated etc. see below). Control participants were recruited from the University of Edinburgh community and via social media and word of mouth. Participants were unpaid and were informed of their ethical rights before taking part, and the study was approved by the local ethics board at Edinburgh University.

**Materials and Procedure**

All subjects took part in the test in the same way, regardless of their status as synaesthete or non-synaesthete. After agreeing to take part, participants were emailed a link containing the web addresses for the experiment and were asked to complete the tasks in their own time. The experiment was presented via Limesurvey (Limesurvey, 2013), a web-based, open source software program. In addition to the main task of mental rotation, participants also completed a series of questionnaires to assess for five types of individual differences: mental imagery, level of education, projector/associator status, number of forms, and whether those forms were 2D or 3D. These tasks are described in turn below, and this represents the order in which tests were completed by our participants.

*The mental rotation task* was taken from Shepard and Metzler (1971; see also Rizza and Price, 2012). The stimuli were illustrated figures representing 3D objects. Each object comprised ten connected cubes which were configured to represent a 3D shape. Each trial presented two of these objects simultaneously (see Figure 2 below): the pair were either the same object rotated in 3D space (‘standard’ rotated), or mirror images rotated (‘mirror’ rotated). The angle of rotation was one of the following: 0°, 20°, 40°, 60°, 80°, 100°, 120°, 140°, 160°, and 180°. Participants were asked to respond by clicking either ‘Yes’ for standard rotated or ‘No’ for mirror rotated. Participants were given 10 practice trials followed by 120 target trials. All responses and reaction times were recorded.

*Figure 2:* Example of mirror image trial from Limesurvey 3D Rotation Experiment.



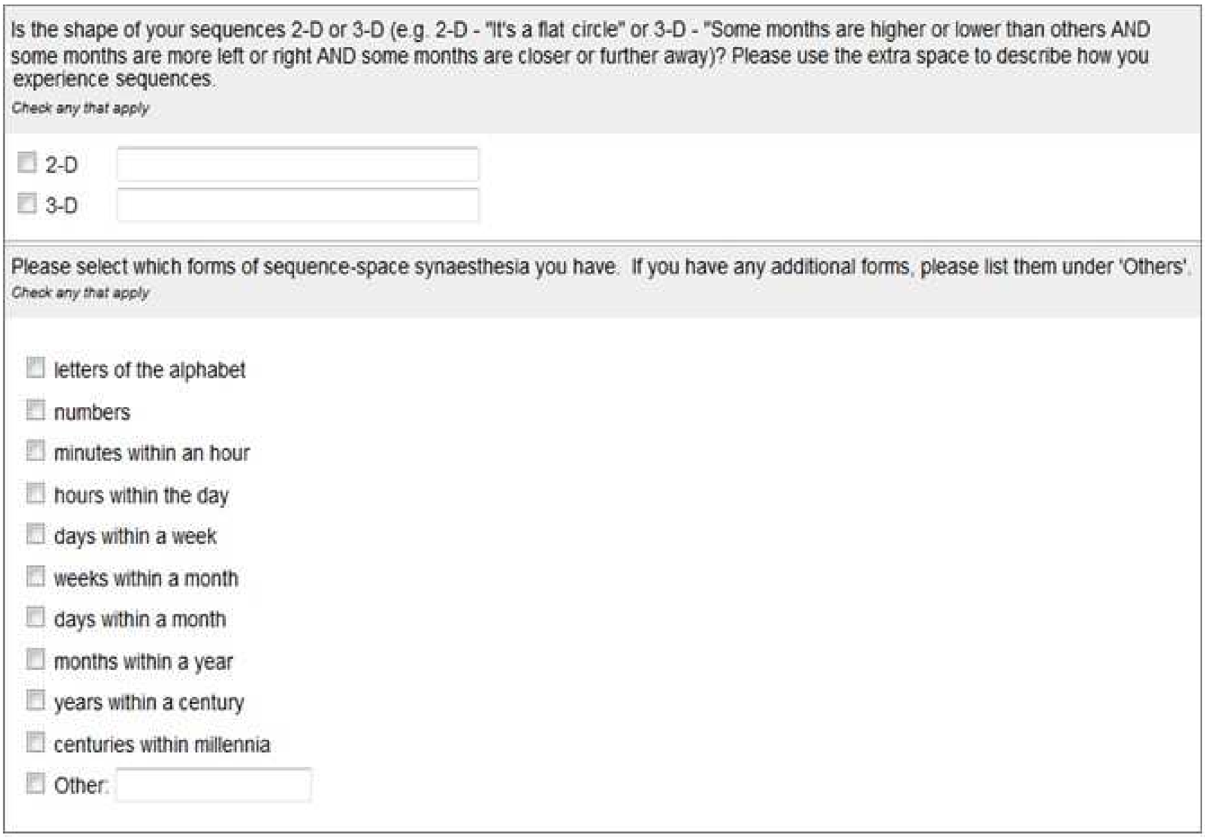

*The Spontaneous Use of Imagery Scale (SUIS)* from Kosslyn, Chabris, Shephard and Thompson (1998) comprises 12 statements to subjectively assess the vividness of one’s visual imagery ability. An example is ‘When I think about visiting a relative, I almost always have a clear mental picture of him or her’. Participants were asked to respond on a 1 to 5 scale with 1 being ‘not appropriate’ and 5 being ‘completely appropriate’, and they selected their answer with a button click from one of five boxes.

*The English Projector/Associator Questionnaire for Sequence-Space Synaesthesia* (Henceforth: *PAQ-SSS/English*; see Appendix) was created for the current study as an adaptation of similar questionnaires developed by Rouw and Scholte (2007) and Rouw (unpublished). The original 12-question questionnaire (Rouw & Scholte, 2007) has been widely used, and was designed to assess the extent to which the coloured graphemes of any given synaesthete are ‘projector’-like or ‘associator’-like. We rewrote this questionnaire to adapt it for sequence-space synaesthetes (rather than grapheme-colour synaesthetes) and we additionally translated from Dutch-to-English a similar adaptation by Rouw herself (unpublished). From this batch of questions, we selected five clear associator and five clear projector questions as the items for our final PAQ-SSS[2]. Hence this questionnaire contained 10 statements overall about the spatial perception of sequences, each with a 5 point Likert scale (scored 0-4) to indicate: Strongly Disagree, Disagree, Neither Agee nor Disagree, Agree, or Strongly Agree. An example of an item that would be positively answered by projector-like synaesthetes was: ‘When I think about a certain sequence (e.g., numbers, months) the accompanying synaesthetic location is not only in my thoughts but also somewhere outside my head’. An example of an item that would be positively answered by associator-like synaesthetes was: ‘I see the synaesthetic location only in my head’. The questionnaire is scored by first averaging the five projector-like items, and then subtracting the mean of the five associator-like items (Rouw, unpublished; Rouw & Scholte, 2007). Hence a positive score indicates a higher projecting ability.

*A Short Questionnaire on the Nature/number of Forms* was completed last. This questionnaire assessed the total number of forms, the triggers for forms, and whether forms were in 2D or 3D space. Participants were simply asked to check a button to indicate their responses (see Figure 3 below), and were also given a text box to list/describe any additional, less common forms they might experience.

*Figure 3:* Screen interface for the *Short Questionnaire on the Nature/number of Forms*.

2 Our participants saw seven additional questions which we henceforth classify as fillers. These items did not make it into our final analysis because we wished to balance the number of associator vs. projector items, and we also required all final questions to be unambiguously within one category or the other. The seven filler items did not fit these criteria.



Is the shape of your sequences 2-D or 3-D (e.g. 2-D - "It's a flat circle" or 3-D - "Some months are higher or lower than others AND some months are more left or right AND some months are closer or further away)? Please use the extra space to describe how you experience sequences.
*Check any that apply*

- ☐ 2-D
- ☐ 3-D

Please select which forms of sequence-space synaesthesia you have. If you have any additional forms, please list them under 'Others'.
*Check any that apply*

- ☐ letters of the alphabet
- ☐ numbers
- ☐ minutes within an hour
- ☐ hours within the day
- ☐ days within a week
- ☐ weeks within a month
- ☐ days within a month
- ☐ months within a year
- ☐ years within a century
- ☐ centuries within millennia
- ☐ Other:

## Results

### *Mental Rotation*

We first assessed the accuracy of responses in mental rotation, comparing synaesthetes to controls. Our data satisfied assumptions of normality in a Shapiro-Wilk's test (both $W$ values > .10) but lacked homogeneity of variances (Levene's test, $p < .05$); so we therefore applied corrected $p$-values and degrees of freedom. The mean accuracy of synaesthetes ($M$ = 92.8%; $SD$ = 4.11) was approximately nine percentage points higher than that of controls ($M$ = 83.9%; $SD$ = 11.27) and this difference was significant in an independent-samples t-test; $t(17.59) = 2.95$, $p(2\text{-}tailed) = .009$, $r = .56$. We next looked at reaction time (RT) data, considering RTs that fell within 2 standard deviations from the mean. An independent-samples t-test confirmed there was no significant difference across groups, hence no speed-accuracy trade-off: synaesthetes $M = 9.05$ sec., $SD = .87$; controls $M = 8.35$ sec., $SD = .97$; $t(17.78) = 1.71$, *p(2-tailed)* = .11, $r = .38$. Finally, we found a positive correlation between angle of rotation for both synaesthetes ($r(8) = .88$, $p < .001$) and controls ($r(8) = .65$, $p < .05$) thus replicating the typically-found increase in response time as a function of angle of rotation found by Shepard & Metzler (1971).

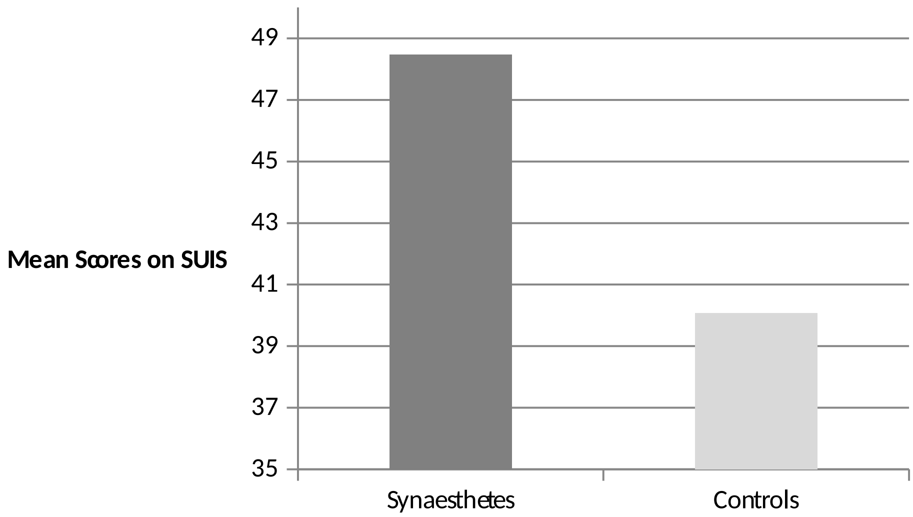
In summary, our results show that while no differences in reaction time were observed across groups in the mental rotation task, synaesthetes responded significantly more accurately[3].

*Visual Imagery*

The SUIS results for each participant were scored by summing individual responses for the 12 items on the questionnaire; higher scores reflect stronger self-reported visual imagery. Scores were normally distributed according to a Shapiro-Wilk's test for normality (both $p$ values > .10) and the assumption of homogeneity of variances was satisfied (Levene's test, $p > .05$). Figure 5 shows that synaesthetes rated their visual imagery ($M = 48.5$, $SD = 5.94$) higher than controls ($M = 40.0$, $SD = 9.57$) and this difference was significant in an independent-samples t-test: $t(28) = 2.89$, *p(2-tailed)* = .007, $r = .48$.

*Figure 5:* Mean scores and standard errors on SUIS Imagery Scale for synaesthetes versus controls; ** p<. 01

3 Our study also included a second task of mental rotation, but this time with simpler materials that were 2D rather than 3D (i.e., eight 2D polygons). These materials were not originally designed to distinguish between groups of participants (see Cooper 1975) and ultimately proved too simple to assess for superior performance in our synaesthete because controls were already at ceiling. The mean accuracy of controls (93.9%; SD = 11.1%) was around ten percentage points higher than in the 3D rotation task, and this made it effectively impossible for our 15 synaesthetes to score significantly higher. In the spirit of full disclosure we report here our participants' mean accuracy (synaesthetes M = 95.1%; SD = 3.6) and RTs (synaesthetes M = 4.37 sec., SD = 2.6; controls M = 4.17 sec., SD = 4.9).




*Individual Differences in Mental Rotation*

In this section we will analyse whether any of the individual differences tested here influenced performance on mental rotation. We generated five scores per synaesthete, for the following five individual differences: Number of forms (max. range: zero upwards); 2D/3D forms (coded as 0=2D; 1=3D); Projector/Associator status from the *PAQ-SSS* (max. range: -4 to +4), Years of Education (max. range: zero upwards), and SUIS imagery score (max. range 12-60). We then ran a multiple regression analysis on our synaesthetes' accuracy scores in mental rotation, to measure the amount of variance explained by these five predictors.

An all-subsets regression method model initially suggested that mental rotation scores were best predicted by a 2-variable model (*PAQ-SSS/English* and 'number of forms') [Adj.$R^2$ = .39, $F(2,12) = 4.50$, $p = 0.03$]. Neither factor significantly accounted for the proportion of variance individually. Based on no significant difference between a two-variable model (*PAQ-SSS* and 'number of forms' as predictors), [$F(1) = 0.78$, $p = .40$], a more parsimonious model using only *PAQ-SSS* scores alone [Adj$R^2$ = .35, $F(1,13) = 8.40$, $p = 0.01$] revealed that being a more projection-oriented synaesthete accounted for 35% of the variance when predicting scores on the mental rotation task. In other words, if both PA score and ‘number of forms’ are analysed together in the same model, a substantial amount of the same variance is explained by both predictors. In summary, our best fit model shows that projector/associator status is a significant predictor of performance in mental rotation: those who were more projector-like were significantly more likely to perform better on mental rotation.

Finally, a series of uncorrected correlation analyses shown in Table 1 also demonstrate that several of our predictors were themselves correlated, and that one of these survived correction (a positive correlation between PAQ-SSS and SUIS).

Table 1 *Correlations among Individual Differences within Synaesthetes*

| | | # forms | SUIS | PAQ-SSS | 2D/3D | Edu. |
|---|---|---|---|---|---|---|
| # forms | *r* | -- | | | | |
| | p | | | | | |
| SUIS | *r* | -.09 | -- | | | |
| | p | .76 | | | | |
| PAQ-SSS | *r* | **-.56*** | **.70**** | -- | | |
| | p | .03 | .005 | | | |
| 2D/3D | *r* | .28 | .51 | .31 | -- | |
| | p | .32 | .06 | .26 | | |
| Edu. | *r* | .38 | -.05 | -.43 | -.21 | -- |
| | p | .16 | .88 | .11 | .46 | |

*Notes: # forms*: Number of forms; *SUIS*: Imagery score; *PAQ-SSS*: Projector/Associator score; *2D/3D.*: 2D or 3D spatial calendar; *Edu.*: Years of education. All ps are shown 2-tailed uncorrected. R values which reach significance at uncorrected alpha levels are shown in bold. With 10 calculated correlations the corrected alpha level for significance is .005.

In summary, we found that of our five individual differences, PAQ-SSS (i.e., projector/associator status) was a significant positive predictor for performance on the mental rotation task: those with more projector-like spatial forms scored significantly better. We also found that synaesthetes with more projector-like forms self-reported higher mental imagery. Finally, we point out that none our analyses indicated mental imagery was itself directly correlated with performance on the mental rotation task.

## Discussion

Our study shows that a group of 15 sequence-space synaesthetes are significantly more accurate in a mental rotation task (and no slower) than a group of 15 matched controls. A similar effect has previously also been shown in a group of five sequence-space synaesthetes by Simner et al. (2009), and in group of 15 sequence-space synaesthetes by Brang et al. (2013). Our current study therefore represents the third instantiation of this effect. One study failed to replicate (Rizza and Price, 2012), with nine sequence-space synaesthetes. This latter study may simply have suffered from low power (i.e., they may have had a type II error, perhaps from small participant numbers, or because they presented only 40 trials) although we have here investigated an alternative hypothesis: that their failure to replicate could be explained by individual differences among synaesthetes sampled for testing. The possibility that individual differences may be at the root of previous conflicts in the literature has also been suggested by Simner (2013) and Price (2013). In the current study we tested this empirically by examining five individual differences in particular: number of forms, whether forms are 2D or 3D, projector-associator status (measured by the PAQ-SSS/English), years of education, and self-reported mental imagery ability (measured by the SUIS). Using these five differences as predictors in a multiple regression analysis, our best fit model showed that projector/associator status is a significant predictor of performance in mental rotation. Thus, better performance in mental rotation tends to come in synaesthetes who projects forms into space; conversely, worse performance tends to come in those who experience their forms only in the mind's eye. We did not find evidence that mental rotation was affected by any other factor (number of forms, 2D/3D forns, education, or SUIS imagery) other than what might be expected from their own inter-factor correlations.

The outcome of our study might shed light on previous controversies since one logical possibility is that Rizza and Price (2012) failed to show an effect because they happen to have recruited more associator synaesthetes, compared to the three other studies in this area (Brang et al., 2013; Simner et al., 2009; and the current study). In fact, a consideration of their recruitment methods does indeed point in this direction. Rizza and Price recruited their subjects by first screening a larger sample of individuals to find the sequence-space synaesthetes from among them. In contrast, the current study, and Simner et al. (2009) used a sample of synaesthetes who had self-referred for study, for example via online portals describing synaesthesia or other self-referral methods. Furthermore, it appears likely that self-referral was also used by Brang et al. (2013) because there are no details of any wide-scale screening in their methods. They key difference between wide-scale screening (Rizza and Price, 2012) and self-referral (as here, also Simner et al., 2009; Brang, 2013) is that the former is likely to recruit more associators, and the latter, more projectors (Simner, 2013). In other words, we suggest that those most likely to self-refer are arguably those who *project* their sequences, since these especially 'strong' experiences might be more obvious to the individual compared to associated forms. In contrast, associators, with their more subtle experiences, may not realise that they possess any extra ability at all, and these individuals may therefore fail to self-refer for experimental testing. They would, however, be recruited if they were specifically approached and asked about their experiences in a detailed questionnaire, as in the wide-scale screening method of Rizza and Price (2012). In other words, we suggest that individual differences among synaesthetes may become exaggerated by different experimental sampling methods, and that self-referral may over-recruit projectors, while wide-scale screening may recruit more associators.

The recruitment differences described here could certainly explain why Rizza and Price (2012) failed to replicate an advantage for sequence-space synaesthetes in mental rotation; their method of sampling would likely have encouraged associator synaesthetes, who are (our data suggest) the worse type of performers in mental rotation. However, we make two important points for consideration: we believe that wide-scale screening is a superior approach when aiming to draw conclusions about *what the average synaesthete experiences*, and for this reason, we suggest that future studies might rely on the methods of Rizza and Price (2012) over self-referral where possible. Second, for the consideration of future studies in this area, we also point out that own cohort here of 15 synaesthetes contained 46% who were projector-like (i.e., they scored > 1 on PAQ-SSS). Although no equivalent empirical data is described in the other studies in this area (including Rizza and Price, 2012), we hope this declaration allows future investigations to meaningfully compare their results to our own.

We end our discussion with a consideration of how performance in mental rotation might relate to abilities in visual imagery versus spatial imagery. The dissociation between visual imagery (i.e., the mental representation of an object), and spatial imagery (i.e., the visualisation of space or object-movement within that space) has been well documented (e.g., Farah, Hammond, Levine & Calvanio, 1988; Thompson, Slotnick, Burrage & Kosslyn, 2009; Luzzatti, Vecchi, Agazzi, Cesa-Bianchi & Vergani, 1998). We have found here that sequence-space synaesthetes self-reported high visual imagery. Although Price (2009) had a similar finding, they also found that their sequence-space synaesthetes (n=12) reported only average *spatial* imagery (in the spatial sub-test of the Object-Spatial Imagery questionnaire; OSIQ-spatial; Blajenkova, Kozhevnikov & Motes, 2006; see also Rizza & Price, 2012). On this basis Price and colleagues speculated that sequence-space synaesthetes should not perform well on mental rotation, theoretically speaking. It is interesting therefore that three studies to date show otherwise (here, Simner et al., 2009; Brang et al., 2013). There are of course only two possible conclusions: either spatial imagery and mental rotation are necessarily related, or they are not. If the former, then we assume that synaesthetes showing superior mental rotation (here, Simner et al., 2009; Brang et al., 2013) would likely have reported high spatial imagery, if asked (we did not question them on spatial imagery due to lack of material availability). If the latter, then superior performance in mental rotation can apparently arise irrespective of self-reported spatial imagery skills, and we review evidence for this in the paragraph below.

A brief review of the literature shows that superior performance in mental rotation might indeed result from high *visual* imagery, even if scores on *spatial* imagery questionnaires are low. First, Borst and Kosslyn (2010) found evidence to suggest that spatial imagery questionnaires such as that used by Price and colleagues (OSIQ-spatial; Blajenkova, Kozhevnikov & Motes, 2006) do not in fact correlate with performance on a series of spatial-type tasks (Paper Folding test, Paper Form Board test, and the visuo-spatial items on Raven's Advanced Progressive Matrices). Although Blajenkova et al. 2006 report that the OSIQ-spatial -- but not OSIQ-visual -- does positively correlate with mental rotation, other evidence suggests that subjects can still score highly on mental rotation from high *visual* imagery. Logie et al. (2011) and Weatherly (1997) reported that high visual imagers (e.g., tested with the VVIQ; Marks, 1973) performed particularly well in mental rotation. We would conclude therefore that scores on the OSIQ-spatial may not reflect absolute performance in mental rotation, either because the rotation task itself can be performed via strong visual imagery, or because the OSIQ-spatial happens to be an inconsistent measure of certain visuo-spatial skills in general. Indeed, only two of the twelve questions in the OSIQ-spatial relate to mentally rotating, and Thompson et al. (2009) have recently suggested that spatial imagery might in fact be two distinct systems, only one of which deals with the mental rotation of objects. We therefore conclude that although the self-reported spatial abilities of our participants are unknown, these may or may not relate to performance in mental rotation, either because the OSIQ may be an inconsistent measure of this type of spatial ability, or because synaesthetes might be able to perform mental rotation reliant on their high visual imagery alone. We did not find a *direct* link here between visual imagery and mental rotation ability, but we did find that those who perform best in mental rotation (projectors) are also those who self-report the highest visual imagery.

In conclusion, we have presented a second replication of a higher accuracy in mental rotation for sequence-space synaesthetes. We linked these results to individual differences within synaesthetes and concluded that those who project their forms into space might be especially accurate in this task. Together with previous findings (Simner et al., 2009; Brang et al., 2013) our data suggest that although synaesthetes who have been tested in mental rotation do overall tend to out-perform controls, this may not always be the case (Rizza & Price, 2012) and that the effect is likely to be absent if the sampling method recruits a large proportion of associator synaesthetes.

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**Appendix.** Projector/Associator Questionnaire for Sequence-Space Synaesthesia (PAQ-SSS/English), adapted from Rouw and Scholte (2007) and Rouw (unpublished). Projector Items are 2,4,6,9,10 and Associator Items are 1,3,5,7,8. There were also seven filler questions which were not analysed either because we ultimately chose to balance the number of associator vs. projector questions in our analysis, or because the content of the filler question was ambiguous between associator/projector.

*For each question, please rate whether you Strongly Disagree, Disagree, Neither Agee no Disagree, Agree, or Strongly Agree*

1. *When I think about a certain sequence (e.g., numbers, months), the accompanying location appears only in my thoughts and not in my head.*

2. *It's as if some sequences (e.g., numbers, months) are actually at an external location.*

3. *When I look at a certain sequence (e.g., numbers, months) written down, the accompanying synesthetic location comes in my thoughts, but on the paper itself, I only see the sequence as it's been printed (e.g., a line of black text).*

4. *When I think about a certain sequence (e.g., numbers, months) the accompanying synaesthetic location is not only in my thoughts but also somewhere outside my head.*

5. *The sequence itself has no actual location I can perceive anywhere, but I am just aware that it is associated with a specific location.*

6. *If I see a sequence (e.g., numbers, months), then the synaesthetic location really is projected into space.*

7. *I do not see sequences literally in a particular location but I have a strong feeling that I know where the sequence would belong (i.e., what location it would have).*

8. *I see the synaesthetic location only in my head.*

9. *If a sequence (e.g., numbers, months) is written on paper, I see the form of my own synaesthetic sequence (e.g., numbers, months) very clearly in the proximity of what's written down (e.g., on top of it or behind it or above it).*

10. *When I think about a specific sequence (e.g., numbers, months), it also appears at an accompanying location somewhere outside my head.*