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# Visuo-spatial representations of the alphabet in synaesthetes and non-synaesthetes

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Visuo-spatial representations of the alphabet (so-called 'alphabet forms') may be as common as other types of sequence–space synaesthesia, but little is known about them or the way they relate to implicit spatial associations in the general population. In the first study, we describe the characteristics of a large sample of alphabet forms visualized by synaesthetes. They most often run from left to right and have salient features (e.g., bends, breaks) at particular points in the sequence that correspond to chunks in the 'Alphabet Song' and at the alphabet mid-point. The Alphabet Song chunking suggests that the visuo-spatial characteristics are derived, at least in part, from those of the verbal sequence learned earlier in life. However, these synaesthetes are no faster at locating points in the sequence (e.g., what comes before/after letter X?) than controls. They tend to be more spatially consistent (measured by eye tracking) and letters can act as attentional cues to left/right space in synaesthetes with alphabet forms (measured by saccades), but not in non-synaesthetes. This attentional cueing suggests dissociation between numbers (which reliably act as attentional cues in synaesthetes and non-synaesthetes) and letters (which act as attentional cues in synaesthetes only).

Visuo-spatial forms are generally considered to be a variety of synaesthesia in which ordinal sequences, such as units of time, numbers, and letters of the alphabet, take on explicit spatial locations in the mind's eye or in peripersonal space (Sagiv, Simner, Collins, Butterworth, & Ward, 2006). There is very little information on synaesthetic spatial alphabets; they are mentioned in passing by Sagiv *et al.* (2006), Seron, Pesenti, Noel, Deloche, and Cornet (1992), and Spalding and Zangwill (1950) as spatial forms that may co-occur with number forms, but have not themselves been the subject of experimental investigation. Spatial alphabets might be just as prevalent as those for numbers or the calendar (Sagiv *et al.*, 2006). However, unlike calendar forms and number forms, there is

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no obvious use for alphabet forms. Units of time in spatial representation have a certain advantage to the synaesthetes who have them: they can be used for planning (Price & Mentzoni, 2008), for manipulation of time series (Mann, Korzenko, Carriere, & Dixon, 2009) or for recall (Simner, Mayo, & Spiller, 2009). Similarly, number forms can be used for calculation (Seron *et al.*, 1992; Ward, Sagiv, & Butterworth, 2009). The spatial alphabet is unlikely to be used frequently in this way because of the rarity of needing to place data in alphabetical order. However, it is still useful to study spatial alphabets as they allow insight into the general processes underlying the initial acquisition, storage and retrieval of this linguistic ordinal sequence. There is also great interest in understanding how numerical cognition is supported (or not) by spatial processes, and learning more about the spatial representation of non-numerical sequences is an important part of that research.

In the general population, there is strong evidence for implicit spatial representations of numbers that influence behaviour but are not consciously reported as a number form. In an odd/even judgement task, the left hand responds more quickly than the right to numerically smaller numbers from the response set, but the reverse is true of numerically larger numbers (Dehaene, Bossini, & Giraux, 1993). This has been termed the SNARC effect (spatial–numerical association of response codes). Similarly in attentional cueing tasks, smaller numbers facilitate detection of subsequent targets on the left whereas larger numbers facilitate detection of subsequent targets on the right (Fischer, Castel, Dodd, & Pratt, 2003). Results such as these are taken as evidence that there is a left-to-right oriented (mental) number line that supports numerical cognition. However, evidence for an equivalent spatial representation of the alphabet in the general population is inconclusive. Dehaene *et al.* (1993) found no equivalent SNARC effect when categorizing letters (using lateralized responses) as belonging to either of the groups A, C, E or B, D, F. Fischer (2003) also failed to find a SNARC effect for letters when participants were asked to point at targets either side of a cueing letter in a consonant/vowel judgement task. One can argue of Dehaene and colleagues' task that not using the full range of the alphabet might diminish any effects to be found; additionally, that the participant pool ($N = 10$) is not large enough, or that the task is rather arbitrary. Gevers, Reynvoet, and Fias (2003) identified and addressed these concerns, instead asking their 24 participants to decide if a letter came before or after O, or whether a letter was a consonant or vowel; they found spatial biases in both of these tasks, consistent with a left-to-right A-to-Z alphabet line. Other evidence for an implicit left-to-right spatial representation of the alphabet comes from patients with visuo-spatial neglect. These patients tend to neglect the left side of physical lines and, hence, bisect lines towards the right of the true centre (Marshall & Halligan, 1990). Analogous effects are found when asked to bisect numbers (e.g., 'what is midway between 4 and 9?', Zorzi, Priftis, & Umiltà, 2002). More recently, these studies have been extended to the alphabet with consistent positive results (e.g., 'what is midway between N and V?', Nicholls, Kamer, & Loftus, 2008; Nicholls & Loftus, 2007; Zamarian, Egger, & Delazer, 2007; Zorzi, Priftis, Meneghello, Marenzi, & Umiltà, 2006).

It has generally been assumed that the same number–space (and letter-space) representations affect performance across a wide range of tasks. An alternative proposal is that many different types of spatial association may be created 'on the fly' according to the demands of the task. In support of this, neglect may affect number bisection tasks but not the SNARC effect (Priftis, Zorzi, Meneghello, Marenzi, & Umiltà, 2006) and a case study of a synaesthete with a right-to-left number form shows a conventional left-to-right SNARC effect (Piazza, Pinel, & Dehaene, 2006). It has recently been suggested that bisection errors of ordered sequence in neglect may reflect spatial working memory limitations rather than a tendency to represent sequences spatially in long-term memory (Doricchi, Guariglia, Gasparini, & Tomaiuolo, 2005). This would explain why letters and numbers behave similarly on these tasks, but not on other kinds of task. Numbers and letters appear to dissociate in their propensity to act as attentional cues in the general population. Fischer *et al.* (2003) found that centrally presented numbers can orient attention by facilitating detection of a subsequently presented target on the left or right, such that small numbers (e.g., 1, 2) directed attention to the left and large numbers (e.g., 8, 9) to the right. Dodd, Van der Stigchel, Leghari, Fung, and Kingstone (2008) failed to replicate this effect with letters acting as cues, except if participants had to make a judgement about the alphabetical position of the letter after each trial (before or after M). Similarly, Casarotti, Michielin, Zorzi, and Umiltà (2007) found that numbers produce lateral shifts of attention in a temporal order judgement task but letters do not. None of these studies directly contrasted the less common, consciously perceived, synaesthetic alphabet forms with the more common implicit spatial associations between letters and space that may be found in the general population. While the two possible ways in which the alphabet can be represented spatially seem very similar, this may not actually be the case. Synaesthetes may have structurally or functionally different brains from non-synaesthetes, and one (indirect) way of assessing which of these is true is to compare synaesthetic alphabet forms to their implicit counterparts.

Why do sequences tend to be represented spatially either as consciously experienced forms (in some synaesthetes) or implicitly (in the neuro-typical population)? One suggestion is that these associations occur because spatial processes and mechanisms for representing ordered series (such as time and number) share overlapping neural substrates. These are generally proposed to reside in the left parietal lobe (Hubbard, Brang, & Ramachandran, 2011, in this issue; Hubbard, Piazza, Pinel, & Dehaene, 2005; Walsh, 2003). The further assumption is that the sharing of this neural substrate is not a coincidence but rather reflects an evolutionary solution for the representation of abstract concepts by employing more ancient mechanisms concerned with spatial cognition. Alphabets may tend to gravitate towards this same mechanism of representation even though they are effectively ordered labels rather than concepts. A somewhat different account has recently been put forward by Eagleman (2009), who argues that spatial forms are cognitively equivalent to the 'structural description' (Humphreys, Riddoch, & Quinlan, 1988) of objects and may be represented within the ventral visual stream. The internal structure of a spatial form (e.g., January on the left, other months arranged in an anti-clockwise ellipse) may be represented in the same way as other multi-part objects (e.g., those that specify the visuo-spatial arrangements of the limbs, tail, etc. of an animal). Agreeing with Hubbard *et al.* (2005), Eagleman (2009) argues that the anatomical closeness of sequential concepts and visuo-spatial processes facilitates the formation of spatial forms but, unlike Hubbard *et al.* (2005), his hypothetical placement of spatial forms is in the (right) temporal cortex rather than the (left) parietal cortex.

According to these accounts, the association between sequence and space reflects functional neuro-anatomy. However, the precise arrangement in space may be moderated by cultural factors or even handedness (Brang, Teuscher, Miller, Ramachandran, & Coulson, 2011). The left–right direction of the SNARC effect is modulated by cultural differences in reading direction (Dehaene *et al.*, 1993; Shaki, Fischer, & Petrusic, 2009). Synaesthetic number forms, in Western participants, usually run from left to right (Sagiv *et al.*, 2006) as do synaesthetic calendar forms (Eagleman, 2009). The internal structure may also be determined by the nature of the concept and the significance attached to points in the sequence. Around 20% of calendar forms are circular or elliptical (Eagleman, 2009) but these shapes are hardly ever found for numbers (Sagiv *et al.*, 2006). In number forms, there is often a break or bend at each decade (10, 20, 30, etc., Sagiv *et al.*, 2006) and spatial forms for days of the week are anecdotally noted to give importance (i.e., more space) to Saturdays and Sundays (Ward, 2008). Many of Galton's (1880b) number forms gave prominence to the number 12. This fact was remarked on by his contemporaries in other countries who did not find this in their samples (e.g., Phillips, 1897) and attributed it to the greater use of duodecimal systems in nineteenth century Britain (e.g., shillings, inches). Some recent computational models attempt to explain these characteristics (Grossberg & Repin, 2003; Makioka, 2009). They use self-organizing networks in which there are initially random connections between numbers and space. An emergent property of these networks is that similar numbers come to be represented in similar regions of space, such that 5 is next to 4 and 6, and so on. Co-occurrence would have a comparable effect, so that January may be next to December (despite being at opposite ends of a sequence) and 1 next to 12 (because they appear together on a clock face). What is unclear about these models is whether the input is numerical magnitude (Makioka, 2009), ordinality, or verbal sequences (Grossberg & Repin, 2003). Galton (1880a) himself believed that number forms start life as verbal–spatial associations that come to incorporate the visual sequence of Arabic digits at a later age:

> 'I believe the forms to have been mnemonic diagrams, invented by the children when they were learning to count *verbally*, the *sounds* of the successive numerals being associated with the successive points of the form. Also, that when the children learned to read, the visual symbols of the numerals quickly supplanted the verbal ones, and established themselves permanently in their place'. (p. 495)

In English-speaking countries, it is common for children to learn the alphabet through the Alphabet Song (Ehri, 2009). This divides the alphabet into mostly rhyming segments: ABCDEFG, HIJK, LMNOP, QRST, UV (alternatively QRS, TUV), WXYZ. This chunking of the verbal sequence is retained into adulthood and affects participants' judgements about letter order. Klahr, Chase, and Lovelace (1983) presented American English-speaking participants with a letter and asked them to say what letter comes before or after it in the alphabet. Performance was slower when judgements crossed chunks (e.g., 'what comes after G?', 'what comes before H?') than occurred within chunks (e.g., 'what comes after F?', 'what comes before G?'). Although this choice of chunking may be culture specific, there may be a general tendency to chunk the alphabet according to general constraints (e.g., ease of breathing, articulation). Scharroo, Leeuwenberg, Stalmeier, and Vos (1994) note that Dutch speakers show inter-subject agreement in their preferences for chunking the alphabet (e.g., at J/K, T/U, W/X) even though these breaks do not agree with those in the English system. Whatever its origin, there are within-culture regularities in the verbal chunking of the alphabet and, if alphabet forms are derived from a verbal code (Galton, 1880b), we may expect to find evidence of this chunking in their visuo-spatial representation (e.g., Makioka, 2009). We assess this in Experiment 1, using a large survey of synaesthetes. In Experiment 2, we examine whether having an alphabet form affects performance on the task of Klahr *et al.* (1983), given that synaesthetes have both a verbal and visual representation of the alphabet. In Experiment 3, we compare more closely how visuo-spatial representations of the alphabet may differ between synaesthetes and the neuro-typical population in tests of attention/gaze cueing and consistency.

## EXPERIMENT 1: GENERAL CHARACTERISTICS OF SYNAESTHETIC ALPHABET FORMS

In this preliminary study, a previous questionnaire item was analysed in which self-reported synaesthetes were asked whether they experienced the alphabet spatially and, if so, to draw or describe it. The characteristics of the forms are analysed here. The prediction is that they will tend to run from left to right, as is found for other forms such as spatial calendars and number lines. If the internal structure is influenced by verbal learning then we further expect deformations in the alphabet form to be concentrated around the pauses in the Alphabet Song.

### Methods

#### *Participants*

At the time of analysis, 474 native English-speaking synaesthetes had completed a questionnaire asking them about various aspects of their synaesthesia (http://www.syn.sussex.ac.uk). Synaesthetes had a mean age of 43.52 years ($SD = 15.68$; range = 12–91) and 383 were female.[1] They had spontaneously contacted our research group over a number of years. They had not been specifically recruited for having this type of synaesthesia and nor had we recruited them via questionnaires in lectures (and so on), which may be likely to elicit false claims of synaesthesia (e.g., Simner *et al.*, 2006). Of these, 358 (75.5%) reported grapheme-colour synaesthesia and 192 had been tested for grapheme-colour consistency using the methods of Eagleman, Kagan, Nelson, Sagaram, and Sarma (2007) or Simner *et al.* (2005). The alphabet forms from 'verified' grapheme-colour synaesthetes did not differ from the others and we pool them here.

In addition, 16 participants were selected who were native German speakers and reported alphabet forms with breaks or changes in direction. German speakers do not have the equivalent of an Alphabet Song.

#### *Materials and procedure*

As part of the Synaesthesia Research Group's initial screening questionnaire, each synaesthete was asked the question 'Do you think about the letters of the alphabet being arranged in a specific pattern in space (e.g., in a line, or circle)?' and asked to indicate on a 5-point Likert scale whether they strongly disagreed, disagreed, neither agreed nor disagreed, agreed or strongly agreed. If they agreed or strongly agreed, they were asked to provide a diagram of this pattern.

The patterns were visually inspected for line breaks, gaps or changes in orientation (hereafter collectively referred to as *features*; see Figures 1a–c, respectively, for examples of these).

### Results

Of the 474 English-speaking synaesthetes who completed the questionnaire, 252 (53.2%) reported an alphabet form that is stable over time and provided a drawing and/or description. A further 40 (8.4%) reported a form but did not supply a complete diagram or description; a further 19 (4.0%) said that the shape of the form was not stable over time; and a further 27 (5.7%) did not answer this particular question.

[1] *Six synaesthetes did not state their date of birth or age and one did not state his/her sex.*

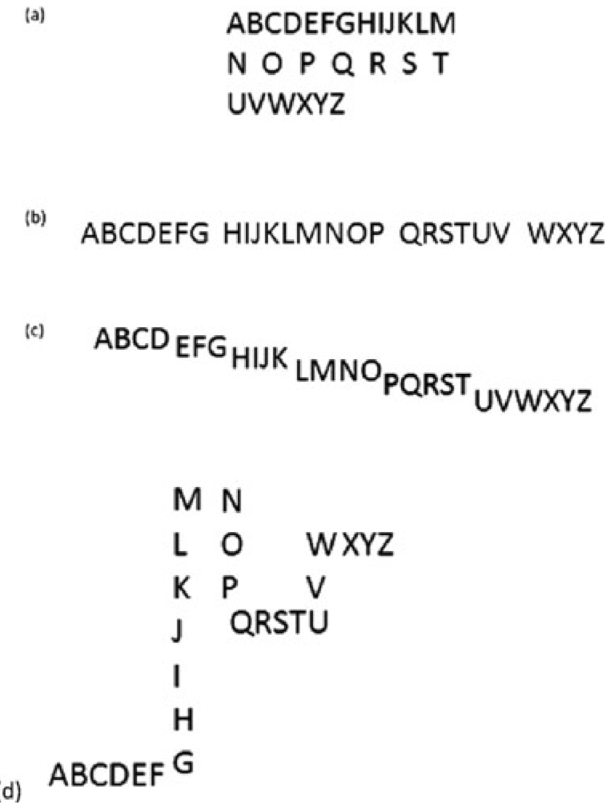


**Figure 1.** (a) CJ's spatial alphabet, with line breaks at M/N and T/U; (b) JD's spatial alphabet, with gaps at G/H, P/Q, and V/W; (c) SS's spatial alphabet, with orientation changes at D/E, G/H, K/L, O/P, and T/U;(d) RH's spatial alphabet with a change of direction at G/H, M/N, N/O, Q/R, U/V, and W/X.

The general characteristics of the alphabet forms from the 252 respondents are summarized in Table 1. The most common configuration is a single unbroken straight line. Most were arranged in a left-to-right direction (73.5%), with only 2.4% reporting a vertical line (the rest were described or drawn as linear but a clear direction was not given, and no synaesthete explicitly reported an alphabet that ran in a right-to-left direction). The next most common configurations were a sudden change in direction without line breaks or gaps, as in the example of RH (see Figure 1d) and a configuration in which the alphabet form contained line breaks, as in the example of CJ (Figure 1a).

In Figure 1a–c, features were coded as existing at the obvious places (e.g., M/N and T/U in Figure 1a, G/H, P/Q, and V/W in Figure 1b). Some synaesthetes reported features in which letters appeared at the corner of a direction change (as in Figure 1d). For the purposes of this analysis, gaps and breaks were marked as existing between the letter on the corner of the curve and the next letter (e.g., the L/M/N change was marked as an M/N change). Additionally, there were some repetitions of letters either side of a gap or line break (e.g., ABCD DEF); these were marked as existing between the second incidence of the letter and the following letter. The positions of features were coded in the 87 synaesthetes who had them (Table 1, last four lines: $46 + 29 + 6 + 6 = 87$), generating a total sample of 263 features. The frequency of features between each letter pair is shown in Figure 2. Binomial distribution indicates that features are significantly

**Table 1.** Self-reports of spatial-alphabet shapes among 252 synaesthetes reporting unchanging spatial alphabets (percentages in parentheses)

| Format of alphabet self-report | Frequency |
|---|---|
| Single, unbroken straight, or curved line of letters (horizontal) | 114[4] (45.2) |
| Single, unbroken straight, or curved line of letters (diagonal) | 18 (7.1) |
| Single, unbroken straight, or curved line of letters (vertical) | 6 (2.4) |
| Linear (unspecified direction) | 24 (9.5) |
| Circular | 2 (0.8) |
| Single, jagged line that changes direction with every letter | 1 (0.4) |
| Sudden direction changes (without gaps or line breaks) | 46 (18.3) |
| Line breaks (without direction changes or gaps) | 29 (11.5) |
| Gaps (without direction changes or line breaks) | 6 (2.4) |
| Combinations of gaps and/or line breaks and/or direction changes | 6 (2.4) |

[4]Twenty-two of these could be classified as diagonal, but the deviation from horizontal is so slight that it is probably a result of inaccurate drawing.

($p < .05$) more likely than chance to occur between letter pairs at seven positions: G/H, L/M, M/N, N/O, P/Q, T/U, and U/V (black columns in Figure 2). Three of these cluster around pauses in the Alphabet Song (G/H, P/Q, and T/U). The other salient aspect, not represented in the Alphabet Song, is for features to concentrate near the letters M and N (at L/M, M/N, and N/O), this being the mid-point of the alphabet.

We were able to obtain 72 features from the German-speaking synaesthetes. Given the relatively small number of features, we did not analyse them over the entire alphabet but rather grouped them into three bins: features occurring at chunk boundaries in the Alphabet Song (G/H, K/L, P/Q, T/U, V/W), around the mid-point (L/M, M/N, N/O) and at the seventeen remaining locations. The data are summarized in Table 2. A chi-square

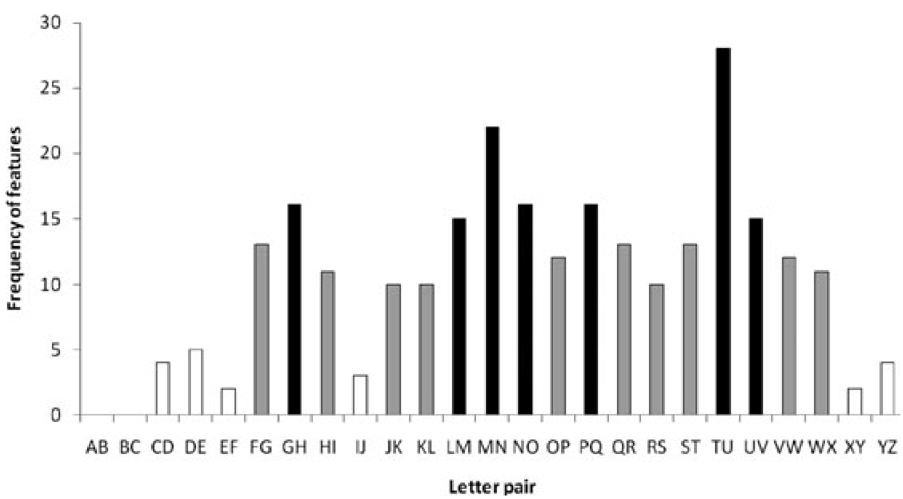


**Figure 2.** Frequency distribution of breaks, gaps and direction changes in spatial alphabets. The dotted line indicates the average distribution across all letter breaks. Black columns indicate significantly higher frequencies of breaks than expected; white columns indicate significantly lower frequencies of breaks than expected; grey columns indicate frequencies that are not significantly different from what was expected.

**Table 2.** Locations of features in English and German synaesthetes' alphabets (percentages in parentheses)

| Feature location | English | German |
|---|---|---|
| Song chunk boundaries | 82 (31.2) | 21 (29.2) |
| Mid-point | 53 (20.2) | 14 (19.4) |
| Elsewhere | 128 (48.7) | 37 (51.4) |
| Total | 263 | 72 |

test showed that there was no difference between observed and expected frequencies ($\chi^2$ (2) = .17; $p$ = .92), indicating that German speakers and English speakers have features in similar places in the spatial alphabet. Nine of the participants reported no awareness of the English Alphabet Song, four were aware of it, and three did not provide information.

## Discussion

In English speakers, although spatial-alphabet forms are idiosyncratic they are not random. Instead, they are constrained by two influences: the chunking pattern of the Alphabet Song, and a tendency to divide the alphabet close to the mid-point. The K/L break expected from the Song may be missing because it is dominated by (or merged with) the mid-point. Similarly, the expected V/W break was absent in the data although the nearby T/U and U/V breaks were found to be represented more than chance would suggest (the latter two may be more significant than the former). This is interesting from a developmental point of view, because the recitation of the Alphabet Song precedes literacy acquisition (Ehri, 2009). This raises the possibility that verbal–spatial synaesthetic associations are established before visual representations of letters are acquired, as proposed by Galton (1880a). This is reminiscent of a single case study by Jarick, Dixon, Stewart, Maxwell, and Smilek (2009; see also Jarick, Jensen, Dixon, & Smilek, 2011, in this issue). This person viewed her spatial calendar form from different perspectives depending on whether she heard or read month names. They speculated that the auditory viewpoint (right-to-left arrangement) may have been acquired first, but reversed to the more conventional left-to-right arrangement during schooling.

However, it seems that exposure to the Alphabet Song is not necessary for features to appear in line with its phrasing, as German synaesthetes' alphabets have features in similar places to English synaesthetes' alphabets. This does not, however, preclude a verbal–spatial arrangement prior to learning the visual appearance of letters, as the pauses of the Alphabet Song neatly divide the alphabet into chunks of two to seven letters. Young children may use this chunking strategy as a memory aid when learning the sounds of the alphabet and then later apply those chunks to a visual representation of the letters.

## EXPERIMENT 2: EFFECTS OF SPATIAL ALPHABETS ON NAVIGATING THE ALPHABET

The consequences of having a spatial alphabet on manipulations involving the alphabet are not yet clear. Examples of such manipulations are ordering according to alphabetical principles, categorizing letters as early or late in the alphabet, and reporting what letter comes before or after another in the alphabet. In the current experiment, we follow the procedure used by Klahr *et al.* (1983) and Scharroo *et al.* (1994) of asking respondents to say which letter comes before or after a given letter. Response times (RTs) showed a series of peaks and troughs corresponding to conventional ways of verbally chunking the alphabet. However, synaesthetes with alphabet forms may be expected to treat this task more like scanning of a mental image (Finke & Pinker, 1982), so we predict their performance to be faster overall. Moreover, we would expect their peaks and troughs to follow the structure of their alphabet form (i.e., requiring internal shifts of attention from one location to another at features) more closely than the putatively verbally based chunks of the Alphabet Song – synaesthete SS (Figure 1c), for example, should show a peak in reaction time at D/E, whereas a control should not. Finally, the previous studies reported that performance tended to be slower at the end of the alphabet, attributing the fact to later items being less well rehearsed. We predict this effect to be diminished or absent if synaesthetes can scan a mental image of the alphabet.

## Method

### *Participants*

Fourteen spatial-alphabet synaesthetes and 14 age-matched controls took part in this experiment. Nine had previously been included in Experiment 1. The mean age of the synaesthetes was 26.29 years ($SD = 9.63$; range = 18–55) and the mean age of the controls was 26.71 years ($SD = 9.47$; range = 18–55).

Three of the synaesthetes reported straight-line alphabet forms, and the remaining 11 reported features in at least three locations. The location of these features was categorized in one of four ways: as crossing chunks (i.e., answering requires using two phrases of the Alphabet Song) within the Alphabet Song but not the spatial form (Song Only, e.g., P/Q in Figure 1c); as crossing chunks within the spatial form (i.e., answering requires using two letters in the alphabet that are either side of a feature) but not the Alphabet Song (Form Only, e.g., D/E in Figure 1c); as crossing chunks that occur both at Song boundaries and form boundaries (Song + Form, e.g., G/H in Figure 1c); and those that do not cross chunks at all (No Feature, e.g., M/N in Figure 1c). For this analysis, data from controls were yoked with those from synaesthetes and split into the same categories.

### *Materials and procedure*

Upon coming to the laboratory for testing, controls were given a brief explanation of spatial-alphabet synaesthesia and asked if they experienced anything similar. Synaesthetes were asked to draw their spatial alphabet before beginning the experiment in order to draw their attention to the possibility of using it during the task.

Following Klahr *et al.* (1983) Experiment 1 and Scharroo *et al.* (1994), we asked participants to sit at a monitor, where they were presented (using E-Prime 2.0) with a fixation cross for 500 ms, followed by an upper case letter of the alphabet. In one task, letters B to Z were presented and the participant was asked to name the letter preceding it in the alphabet (*backwards task*); in the other task, letters A to Y were presented and the participant was asked to name the letter following it in the alphabet (*forwards task*). Participants gave their responses into a microphone; RTs were recorded using a serial response box attached to the microphone. In each task, each letter was presented five

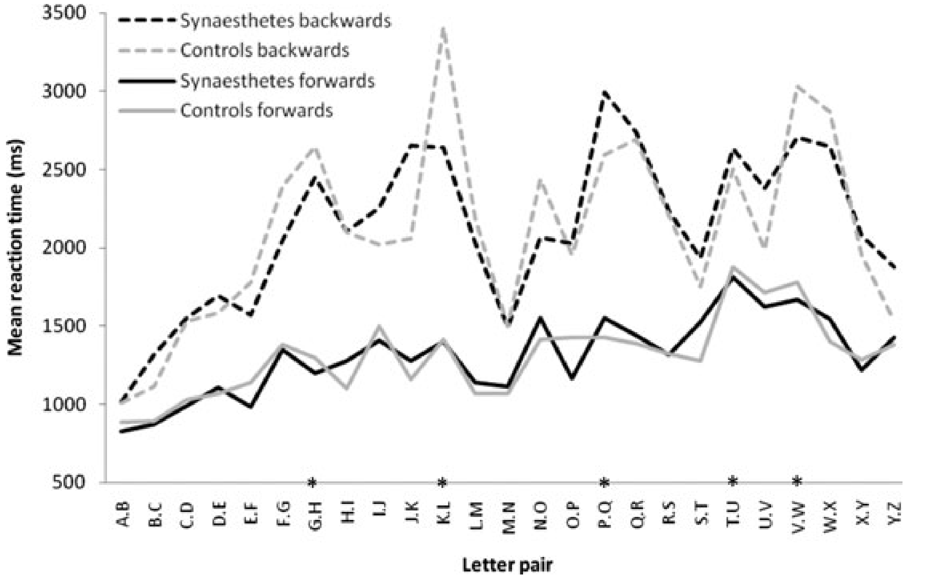


**Figure 3.** Mean reaction times of synaesthetes and controls asked to state what letter of the alphabet came before (backwards) or after (forwards) a visually presented letter. 'Letter pair' indicates the presented and target letter (e.g., A.B indicates A was presented and B the target in the forwards task, and vice versa in the backwards task). * indicates position of chunking boundaries in the Alphabet Song.

times in a random order, for a total of 125 trials. The order of tasks was counterbalanced so that half the participants did the forwards task first and half did the backwards task first. Synaesthete-control pairs always did the tasks in the same order.

Before analysing the data, trials in which the microphone had failed to register a response, in which the participant had made an error, or which had a RT of less than 300 ms were removed. Altogether, 13.1% of the data were removed.

## Results

Figure 3 shows the mean RTs for synaesthetes and controls in both the forwards and backwards tasks. The RTs show peaks and troughs that tend to coincide with the structure of the Alphabet Song as noted by Klahr *et al.* (1983), the effect being more pronounced in the more difficult backwards task. In the first analysis, the overall performance of synaesthetes versus controls was compared in a 2 × 2 × 25 mixed ANOVA on group (synaesthete, control), task (forwards, backwards), and position in the alphabet (A/B to Y/Z). As expected, there were main effects of task ($F(1, 21) = 72.14$; $p < .001$) and position ($F(24, 54) = 10.18$; $p < .001$) and these two main effects interacted ($F(24,504) = 4.68$, $p < .001$). However, there was no evidence that synaesthetes' performances significantly differed from controls': that is, no main effect of group ($p = .86$) and no interactions between group and task ($p = .66$) or group and position ($p = .49$).

To test for differences in increases in RT across the alphabet in synaesthetes and controls, regression slopes were calculated for each individual's RTs against position in the alphabet. Slope values were then compared against 0 (i.e., no increase in RT) using a one-sample *t*-test and between the two groups using a between-subjects *t*-test. Both mean slopes were positive and significantly different from 0 (*p*s $< .001$) but mean slopes

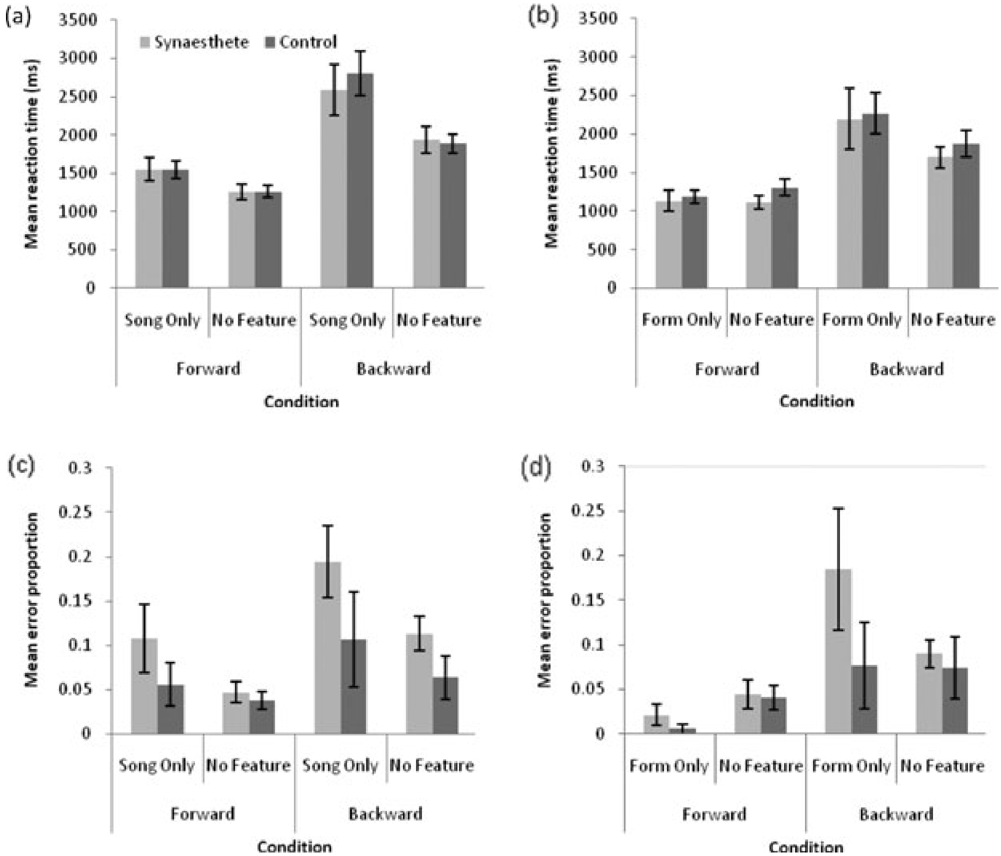


**Figure 4.** Mean reaction times of synaesthetes and controls when compared on (a) Song Only/No Feature and (b) Form only/No feature letter pairs; error rates for (c) Song Only/No Feature and (d) Form only/No feature letter pairs. Error bars show $\pm$ 1 SEM.

did not differ between groups (*p*s > .4), indicating that synaesthetes and controls find the task equally and increasingly difficult towards the end of the alphabet.

Given the idiosyncratic nature of the alphabet forms in this study, a second analysis compared performance between synaesthetes and controls at critical positions in the alphabet. This is summarized in Figure 4. The data were analysed in two $2 \times 2 \times 2$ mixed ANOVAs contrasting group (synaesthete, control), task (forwards, backwards), and letter pair type. Given that some features were present in some synaesthetes and not in others, the number of participants in each analysis differed. There were 14 synaesthetes/controls for the comparison of 'Song Only' with 'No Feature' and 10 synaesthetes/controls for the comparison of 'Form Only' and 'No Feature'. Comparing 'Song Only' positions with 'No Feature', there was a significant main effect of letter pair type ($F(1, 26) = 31.00$; $p < .001$)) showing that people are slower when they need to find letters across verbally defined chunks (as in Klahr *et al.*, 1983) but, contrary to our hypothesis, the effect was equally as strong in synaesthetes as controls (no interaction or group effect). Comparing 'Form Only' positions with 'No Feature' revealed a significant main effect of letter pair type ($F(1,18) = 4.59$; $p < .05$) and a significant interaction between letter pair type and task ($F(1,18) = 8.72$; $p < .05$), due to 'No Feature' pairs being reacted to more quickly than 'Form Only' pairs in the backwards task but, crucially, there were no differences between groups and no interactions with group. (The data from 'Song and Form' features were not analysed as there is no way of knowing whether any differences are due to the Song or the form.)

When the same analyses were performed on error rates, significant ($p$s < .05) effects of task were found, as more errors were made in the backwards than in the forwards task, and more errors were found to be made for 'Song Only' letter pairs than for 'No Feature' pairs ($F(1,24) = 11.07$; $p < .01$). There were no significant main effects or interactions involving group, again suggesting that synaesthetes and controls perform this task in the same way. This may be due to the modality in which the stimulus was presented (if alphabet forms are recruited less by visual presentation of letters), or to the modality in which the response was made (a verbal response may not recruit as strong a representation of the form as a gaze or finger movement).

In summary, there is no evidence that people with an alphabet form perform this task by scanning a 'mental image' rather than by retrieval from a conventionally chunked verbal code.

### Discussion

This experiment replicates previous findings by Klahr *et al.* (1983) but fails to find any difference between synaesthetes reporting a visuo-spatial representation of the alphabet and controls who do not. Our interpretation is that synaesthetes rely on their verbal representation of the alphabet for this task, as do controls. Even if they relied on a local portion of the form, we would expect their performance to be enhanced, unless visualization time is very slow. It is to be noted that they were not explicitly instructed to use a non-verbal strategy, but our hypothesis was that such a strategy would be automatically evoked in these individuals and would lead to benefits over conventional verbal strategies. This does not appear to be the case. Whether or not variations in the task format could spontaneously induce a change in strategy is unknown. In this task, participants were presented with centred letters and asked to give a verbal response. Alternative procedures could be to present stimuli verbally (as shown by Jarick *et al.*, 2009, presentation modality may alter use of spatial forms);[2] to present pairs of letters ('is GH in the correct order?') rather than having them generate a letter verbally ('what comes after G?'); or to present single probe letters in positions of the screen consistent with their internal representation. Of course there is another explanation that cannot be ignored at this stage: namely that the participants with synaesthesia are no different from controls. Evidence from Experiment 3 speaks against this view.

## EXPERIMENT 3: CONSISTENCY AND ATTENTIONAL CUEING

Tests of consistency are considered the 'gold standard' for testing the reality of synaesthetic perceptions, because they are so hard to circumvent (Rich, Bradshaw, & Mattingley, 2005). The synaesthete is presented with the inducer and asked to state the location, colour, taste, etc., of the concurrent; they are then retested weeks or months later without warning. Controls, on the other hand, are asked to act 'as if' they have spatial synaesthesia and know they are to be retested only a few days later. In the spatial

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[2] *We thank an anonymous reviewer for raising this possibility.*

domain, consistency has previously been measured by asking participants to project the shape of their form onto a computer screen (Brang, Teuscher, Ramachandran, & Coulson, 2010; Piazza *et al.*, 2006; Smilek, Callejas, Dixon, & Merikle, 2007). In the first part of this experiment, we follow the same general protocol but use eye movements to the location rather than a mouse click.

In the general population, numbers can act as attentional cues to left or right space depending on their numerical magnitude (Fischer *et al.*, 2003) and can induce an oculomotor bias to the left or right side in SNARC tasks (Fischer, Warlop, Hill, & Fias, 2004). In synaesthetes with calendar forms, a centrally presented month (e.g., January) can direct attention towards or away from a subsequent visual target according to the idiosyncrasies of their own spatial configuration (Jarick *et al.*, 2009; Price & Mentzoni, 2008; Smilek *et al.*, 2007). However, insofar as it has been assessed, there was no evidence that controls had a left-to-right oriented calendar (Price & Mentzoni, 2008). Similarly for letters, Dodd *et al.* (2008) found no evidence that letters act as attentional cues (except when the cueing trial was immediately followed by an alphabetic order judgement). We therefore expect to find an attentional cueing effect to letters in the synaesthetes with alphabet forms that run from A to Z in alphabetical order in the horizontal dimension, but none (or a weaker one) in the controls. The experiment below is conceptually related to those summarized above but uses saccades to a lateralized target rather than target detection with a button press.

## Methods

### *Participants*

Twenty spatial-alphabet synaesthetes and 20 age-matched controls took part in the first part of this experiment (nine had participated in Experiment 1). The mean age of the synaesthetes was 30.75 years ($SD = 12.96$; range = 18–60) and the mean age of the controls was 30.45 years ($SD = 13.26$; range = 18–65). The experiment consisted of a test of consistency and then, for the 13 synaesthetes with an alphabet that ran from A to Z in the horizontal direction (and their yoked controls), an attentional cueing test. Twelve pairs of synaesthetes and controls returned for the second part of the experiment, which was a retest of consistency over a longer interval. The mean number of days between testing for controls was 17.25 ($SD = 6.06$; range = 14–32) and for synaesthetes it was 85.67 ($SD = 17.34$; range = 64–119).

### *Materials and procedure*

These studies were run using Experiment Builder and eye movements were recorded with Eyelink II (SR Research, Ontario, Canada). This has a spatial resolution of approximately 0.25° and a temporal resolution of 2 ms. Participants were seated on a modified office chair that prevented any rotational movement, approximately 70 cm from the computer screen. Stimuli were displayed on a 21 in. CRT monitor at a refresh rate of 100 Hz and a resolution of 1,280 × 1,024 pixels.

Before starting the consistency test, controls received a brief explanation of spatial-alphabet synaesthesia and were asked to imagine that they had a two-dimensional spatial alphabet (in any form the participant chose) for the duration of each testing session. Controls were warned that they would be retested on the same experiment in approximately 2 weeks' time. Synaesthetes were not warned that they would be retested in approximately 3 months' time. A brief 9-point calibration was carried out before the

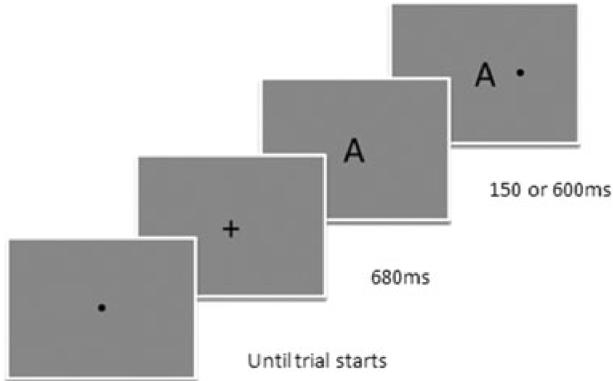


**Figure 5.** Format of presentation for trials in the attentional cueing experiment, with A used as an example letter.

experiment and repeated if necessary between blocks. Each trial was preceded by a brief drift-correction procedure. Participants were asked to 'project' or 'imagine' their spatial alphabet on the computer screen in front of them, which was entirely white except for a black central fixation dot. After participants heard a letter read aloud, the trial began. A blank screen was displayed for 5,000 ms and participants moved their eyes to the location where they had mentally projected or imagined the given letter and focused at this location on the computer screen until the fixation dot reappeared. Each letter of the alphabet was probed twice (in a pseudo-randomized order with the constraint that the same letter was never spoken twice in a row) for a total of 52 trials.

The attentional cueing experiment was conducted in the first session only, after the consistency experiment. The same calibration and drift-correction procedures were used as in the consistency experiment. The procedure for each trial is summarized in Figure 5. During the experiment, the participant saw a central dot until the trial started, followed by a central fixation cross for 680 ms and then one of four centrally presented capital letters. Finally, at a stimulus onset asynchrony (SOA) of 150 or 600 ms, a target dot appeared to the left or right of the letter. Participants were asked to saccade to the target dot as quickly and as accurately as possible after it appeared. Four letters of the alphabet were selected for each participant. Each letter was followed by a target to the left and right equally often, and the SOA was orthogonal to the target side. Each type of trial (one of four letters, left/right, short/long SOA) was presented 10 times, making a total of 160 trials. An additional 16 trials were added as practice trials. Trials were presented in two blocks of 80, with further breaks if the participant asked for them.

## Results

For the consistency test, two sets of data (one synaesthete's and one control's, both in the first part of the experiment only) were removed from analysis due to a technical fault. For each trial, the longest fixation period and the associated pixel co-ordinates for this period were determined. For synaesthetes the mean longest fixation time was 2,663 ms (SEM = 253) and for controls was 2,694 ms (SEM = 231); these means did not significantly differ. The average distance, in pixels, between longest fixations to the same projected letter was calculated for trials within sessions (all participants) and across

**Table 3.** Comparison of synaesthete and control performance on within-session and across-session distance using one-tailed independent measures $t$-tests

| Comparison | Synaesthete mean (SEM) | Control mean (SEM) | degrees of freedom | $t$-value |
|---|---|---|---|---|
| Within-session distance | 105 (17) pixels | 128 (15) pixels | 36 | 1.00 |
| Across-session diagonal distance | 102 (15) pixels | 155 (23) pixels | 22 | 1.93* |

*Note*. Standard errors of the mean (SEMs) are given in brackets. Asterisks by $t$-values indicate significance at the .05 level.

sessions (for those who came back in session 2). These results are summarized in Table 3. Synaesthetes were more consistent than controls both within and across sessions, though this only reached significance across sessions.

For the attentional cueing task, trials in which an error occurred were removed (e.g., an eye movement away from the target), as were those with a RT of less than 80 ms. Data were split into groups by SOA; outliers beyond three standard deviations from the mean were removed and this procedure was repeated until no outliers remained. For each participant and each SOA, difference in RT (dRT) between right and left responses was calculated and regressed on alphabetical position. This method is frequently used to analyse the SNARC effect (for a discussion of the advantages of this method, see Fias & Fischer, 2005). It enables an assessment of relative differences between leftwards and rightwards effects and avoids the need to categorize each trial as 'left' or 'right'. A slope of, say, $-1$ ms implies an estimated RT difference over 26 letters of 26 ms. That is to say, it would take 13 ms longer to respond to Z with the left hand than with the right hand, 12 ms longer to respond to Y, 11 ms for X, etc. Conversely, it would take 13 ms longer to respond to A with the right hand than with the left hand, 12 ms for B, 11 ms for C, etc. The data are summarized in Figure 6.

One-sample $t$-tests can be used to ascertain whether the slopes differ from an expected value of 0. Only in the 600-ms SOA condition did synaesthetes show an effect of spatial cueing ($M = -1.75$; $t(12) = 2.75$, $p < .05$), although the 150-ms SOA condition approached significance ($M = -.83$; $t(12) = 2.02$, $p = .07$). For controls, neither the 600 ms ($M = -.45$; $t(12) = 1.29$, $p = .22$) nor the 150 ms ($M = .11$; $t(12) = .33$, $p = .75$) was significant. A 2 $\times$ 2 mixed ANOVA was used to compare slopes for different groups (synaesthete/control) and SOAs (150/600 ms). A significant main effect of group ($F(1,24) = 4.59$; $p < .05$) was found, caused by synaesthetes' slopes being larger than the controls'. There was also a marginally significant interaction between SOA and group ($F(1,24) = 4.23$; $p = .05$), caused by synaesthetes' slopes being more negative in the 600-ms condition than in the 150-ms condition, while the controls showed the opposite pattern.

## Discussion

The findings of the first part of the experiment suggest that synaesthetes with alphabet forms tend to be more consistent in their spatial placement of letters than controls instructed to imagine an alphabet form. This is consistent with other studies using a similar methodology for calendar forms (Brang *et al.*, 2010; Piazza *et al.*, 2006; Smilek *et al.*, 2007) and number forms (Piazza *et al.*, 2006), though our methodology is somewhat different in that we used gaze fixation rather than mouse movement as

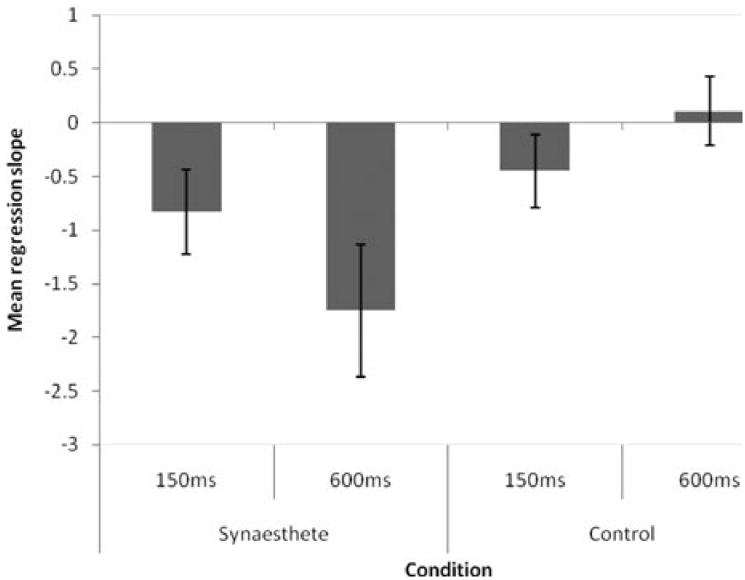


**Figure 6.** Mean regression slopes (in milliseconds) for dRT on alphabetical position in synaesthetes and controls at 150 and 600 ms SOAs. A negative slope indicates faster reactions to right-side targets with letters early in the alphabet and left-side targets with letters late in the alphabet; positive slopes indicate the reverse. Error bars show $\pm$ 1 SEM.

the dependent measure. It is also consistent with the suggestion that sequence forms are represented in the brain as objects with a fixed internal structure, but with some variability in where these structures may be placed relative to the observer (Eagleman, 2009).

The results of the second part of this study indicate that letters can act as attentional cues but only in synaesthetes with alphabet forms, not in non-synaesthetes. Our results suggest that attentional cueing from letter stimuli is greater at long rather than short SOAs, suggesting that the association may be weaker and/or less automatic. However, Smilek *et al.* (2007) used the same SOAs and noted a comparable effect at both. The extent to which sequences (as against more perceptually based cues, such as arrows) are 'early' or 'late' attentional cues could be determined using ERPs (event-related potentials). Teuscher, Brang, Ramachandran, and Coulson (2010) recently report ERP evidence consistent with late attentional cueing (600–900 ms post-cue onset) for month names in synaesthetes with calendar forms, but no cueing effects for controls.

## GENERAL DISCUSSION

This study documents, for the first time, the characteristics of synaesthetic alphabet forms. As with other synaesthetic sequences in Western samples, they tend to be directed from left to right and are most frequently linear. However, the proportion of non-linear forms with various features in them (gaps, bends, or breaks) is significant. They are comparable to features in number forms, which tend to be found at particular places such as at 12 (e.g., Galton, 1880a) or at decades (10, 20, etc.). However, in alphabet forms they appear to be related to conventional ways of reciting the alphabet such as the Alphabet Song. For example, alphabet forms frequently contain a feature at the G/H boundary where 'G' is the last letter of the first phrase of the Song, and 'H' is the first letter of the next phrase. In addition, features are found around the mid-point of the alphabet (the letter M), which we assume derives from spatial constraints (to reduce the length) rather than from recitation. We predicted that speakers of other languages who do not learn using this Song would not show features at these boundaries. However, German synaesthetes with alphabet forms showed a similar trend to native English speakers. Cultures, including the German one, that do not learn the alphabet via an Alphabet Song still show some within-culture agreement as to how to divide the alphabet into chunks (Scharoo *et al.*, 1994), and it is possible that similarities across cultures emerge due to common articulation, breathing, and memory constraints. Thus, English speakers explicitly recall the Alphabet Song, but Germans may obey similar rules when reciting the alphabet, even in the absence of the Song. In Experiment 2, we hypothesized that, if synaesthetes can scan a mental image of the alphabet, they should be faster at deciding which letter comes before or after a probe. However, synaesthetes performed no differently from controls, suggesting that both relied on a verbal strategy to perform the task. In Experiment 3, we demonstrated that synaesthetes with an alphabet form show greater spatial consistency than non-synaesthetes given imagery instructions, and show evidence of attentional cueing (making lateralized saccades after a non-predictive letter prime), unlike non-synaesthetes.

In the wider literature, there is a debate about whether letters and numbers have equivalent spatial associations or whether number–space associations are special by virtue of the fact that they represent magnitude (or cardinality) in addition to the ordinal information common to other sequences. For example, one suggestion is that the number–space associations derive from the spatial association between the concepts 'small' and 'big' with 'left' and 'right' (Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006). Given that letters and the calendar sequence cannot be ranked by size, they may be less likely to take on this association. Three kinds of task have been used in the literature to compare numbers with other types of sequence:

Tasks in which a stimulus (e.g., a letter or number) is presented and is required to be categorized in some way, making a lateralized response. In this kind of task, the stimulus is task relevant (although its magnitude or ordinality may or may not be). The classic example is the SNARC effect for numbers (Dehaene *et al.*, 1993) and another is deciding whether a stimulus comes before or after some fixed value (e.g., 5).

Tasks in which a stimulus (e.g., a letter or number) is presented but is not directly relevant to the task (insofar as it does not require a response to it). An example would be attentional cueing paradigms in which letters or numbers act as non-predictive cues for some later event (e.g., Fischer *et al.*, 2003).

Tasks involving bisection of a sequence from two given stimuli, typically in patients with neglect arising from neurological damage (e.g., Zorzi *et al.*, 2006).

In all three types of task, numbers show evidence of having an associated spatial representation (e.g., Fias & Fischer, 2005). However, the evidence for other sequences is inconclusive. For months of the year, Gevers *et al.* (2003) reported a SNARC-like effect when respondents were asked to decide if a month occurs before or after July (for days of the week, Gevers, Reynvoet, & Fias, 2004) but Price and Mentzoni (2008) failed to find this effect in the comparable task of asking participants whether a month is in the first or second half of a year. They also failed to find an effect in non-synaesthetes asked to decide whether the number associated with a month (e.g., February = 2) is odd or even (Price & Mentzoni, 2008). Such effects are found for synaesthetes with calendar forms and the spatial association follows the idiosyncrasies of their form (Price & Mentzoni, 2008).

Interestingly, such effects can be found in non-synaesthetes when they are instructed to imagine a calendar form (Price, 2009). This suggests that the key difference between synaesthetes and non-synaesthetes may lie in the habitual, as opposed to short-term, use of sequence–space associations. Similarly, months of the year act as attentional cues for synaesthetes with calendar forms but not for non-synaesthetes (Smilek *et al.*, 2007).[3] Zamarian *et al.* (2007) found that months of the year do not show a rightwards bisection error in neurological patients with neglect. One explanation for the discrepancy between months and numbers is that the usual spatial representation for the calendar is circular rather than linear (Brang *et al.*, 2010; but see Eagleman, 2009). Another possibility is that normative spatial representations of the calendar are more likely to shift in perspective (e.g., so past months are on the left, future months on the right). Either way, synaesthetes with calendar forms show evidence of time–space associations that are either weaker or absent altogether in non-synaesthetes.

The evidence for a normative left–right arrangement of the alphabet in non-synaesthetes is more convincing, but falls short of that described for numbers. Letters tend to show the same kinds of neglect bisection errors as numbers (e.g., Zorzi *et al.*, 2006), but it is unclear whether this reflects the use of long-term sequence–space associations or whether it reflects a temporary demand on spatial working memory for the specific purposes of this task (Doricchi *et al.*, 2005). In a SNARC-like task, Gevers *et al.* (2003) found evidence of a left–right alphabet–space association in a consonant/vowel judgement task but Fischer (2003) did not. Both Fischer *et al.* (2003) and Dodd *et al.* (2008) found no evidence that letters can act as attentional cues, although Dodd *et al.* (2008) found this only when participants had to make a subsequent ordinal judgement about the letter. None of these studies contrasted non-synaesthetes with synaesthetes with alphabet forms; our study is the first to attempt this. We replicate the findings of Fischer *et al.* (2003) and Dodd *et al.* (2008) that letters do not normally act as attentional cues in non-synaesthetes but show, for the first time, that they do in synaesthetes with alphabet forms. It would be interesting to repeat other studies in the literature (e.g., Gevers *et al.*, 2003) contrasting synaesthetes with non-synaesthetes. It is possible that some previous findings have been biased by the presence of people with sequence forms in the sample.

It could be said that having spatial forms for letters or the calendar may serve to make these sequences more 'number-like'. SNARC-like and attentional cueing effects, reliably found for numbers in non-synaesthetes, are not reliably found for letters and months in non-synaesthetes. But they are reliably found in synaesthetes with calendar forms (e.g., Price & Mentzoni, 2008; Smilek *et al.*, 2007) and alphabet forms (as shown here). This suggests that these individuals, but not non-synaesthetes, have long-term visuo-spatial representations of these sequences that others do not normally possess, except in the case of numbers.

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[3] *Smilek et al. (2007) did not analyse their control data to test for a left–right arrangement of months. We have replicated their paradigm with non-synaesthetes but found no evidence of a left–right arrangement of months.*

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