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Temporal sequences, synesthetic mappings, and cultural biases: The geography of time

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ABSTRACT

Time–space synesthetes report that they experience the months of the year as having a spatial layout. In Study 1, we characterize the phenomenology of calendar sequences produced by synesthetes and non-synesthetes, and show a conservative estimate of time–space synesthesia at 2.2% of the population. We demonstrate that synesthetes most commonly experience the months in a circular path, while non-synesthetes default to linear rows or rectangles. Study 2 compared synesthetes' and non-synesthetes' ability to memorize a novel spatial calendar, and revealed better performance in synesthetes. The capacity to learn mappings between arbitrary spatial forms and temporal sequences is present in all individuals, and time–space synesthetes' enhanced visuo-spatial memory abilities may underlie their creation of idiosyncratic spatial calendar forms.

1. Introduction

Over the last decade there has been an increasing interest in synesthesia, a condition in which perceptual experiences or concepts in one domain or modality automatically evoke experiences in other modalities (e.g. colors evoked by sounds or tastes). A wealth of studies have focused on a common variant of this phenomenon known as grapheme-color synesthesia, in which particular numbers or letters consistently evoke very specific colors (e.g., Brang, Edwards, Ramchadran, & Coulson, 2008; Hubbard, Arman, Ramachandran, & Boynton, 2005; Rouw & Scholte, 2007; Sagiv, Heer, & Robertson, 2006; Ward & Mattingley, 2006). In the present study, we investigate a type of synesthesia that seems particularly related to common non-synesthetic associations between experiences and conceptions of temporal sequences, and those of spatial relationships. In so-called time–space synesthesia, individuals report that time units, such as the months of the year, days of the week, and other abstract sequences, are experienced as having a spatial layout. These representations may have a two- or three-dimensional form, and are sometimes colored (Cytowic, 1989/2002; Smilek, Callejas, Dixon, & Merikle, 2007). The earliest known description of this type of synesthesia was provided by Galton (1883/1907:87):

> 'The months of the year are usually perceived as ovals, and they . . . often follow one another in a reverse direction to those of the figures on the clock . . . It is a common, peculiarity that the months do not occupy equal spaces, but those that are most important to the child extend more widely than the rest. There are many varieties as to the topmost month; it is by no means always January.'

Time–space synesthesia is particularly intriguing because of its potential connection to conventional time–space mappings used in everyday life. There is extensive evidence that we talk about the concept of time in spatial terms (see Lakoff and Johnson, 1980, for the original proposal of the conceptual metaphor "time is space"). Further, recent experiments show

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that reasoning about time can be directly affected by reasoning about space (Boroditsky, 2000; Boroditsky & Ramscar, 2002; Casasanto & Boroditsky, 2008; Gentner, Imai, & Boroditsky, 2002; Núñez, Motz, & Teuscher, 2006). This body of research suggests that time–space mappings are not only observable in our language (in expressions such as ‘‘time is passing” or ‘‘events are approaching”), but that they are psychologically real, manifest in both linguistic and non-linguistic behavior (e.g., Boroditsky, 2000; Casasanto & Boroditsky, 2008; Gentner et al., 2002), as well as brain responses (Teuscher, McQuire, Collins, & Coulson, 2008).

Besides conceptual mappings observed in human language and behavior, time–space mappings are also evident in cultural artifacts, or what Hutchins (2005) calls ‘‘material anchors,” such as calendars and clocks, which facilitate the projection of spatial concepts into a conceptual blend from which our concept of time emerges (Fauconnier & Turner, 2008). For example, we use wall calendars where the days, weeks, and months, are arranged in a rectangular grid; we use personal planners with varying horizontal or vertical layout of days, weeks, and months; and we use analogue clocks, in which particular spatial locations on the clock-face are assigned to specific hours, minutes, and seconds (see Williams, 2004, for a detailed analysis of the kinds of embodied image schemas that may be required for perceiving the clock structure and reading the clock). Hutchins proposes these cultural artifacts support our construction of meaning, in that the material structure anchors the conceptual blend, stabilizing and maintaining the set of conceptual relations during subsequent reasoning or computation (2005). They also support cognitive activity by serving as external memories and computational tools (Williams, 2004).

As time–space mappings have received much less attention than other synesthetic associations, we describe software developed in our laboratory, which was designed to characterize the phenomenology of the mappings in verified time–space synesthetes and compare them to two sorts of controls, potential synesthetes who reported that they associate a particular spatial form with the months of the year, and non-synesthetes who denied having any such intuitions. Potential synesthetes represent an interesting intermediate case as they apparently share some of the experiential components of this condition, but fail to display the consistency that is the hallmark of synesthesia. Study 1 describes the spatial calendars reported by both verified synesthetes and potential synesthetes and compares them to those produced by non-synesthetes asked to come up with a spatial arrangement for months of the year.

One outcome of Study 1 was the observation of a greater proportion of roughly circular-shaped calendars in verified synesthetes than in either of the control groups. In Study 2 then we focused on verified synesthetes with circular calendars, and evaluated their ability to reproduce a memorized calendar whose orientation differed from their own. Study 2 thus compared verified synesthetes' ability to reproduce their own spatial calendar with their performance on a memorized calendar of opposite orientation; this in turn was compared to non-synesthetes' performance on the same memorized calendars.

2. Study 1

Studies investigating grapheme-color synesthesia as well as other variants have commonly separated synesthetes from controls by combined subjective report and increased consistency; frequently only being considered ‘verified’ synesthetes if their consistency was significantly enhanced over that of control subjects (Simner et al., 2006). Aligning with these standards, we separated participants into three groups, based first on subjective report, then secondly, on performance. The first group, *non-synesthetes*, denied experiencing the year as a spatial sequence. The second group, *potential synesthetes*, proclaimed the experience of a spatial form but performed similarly to non-synesthetes on the consistency task. Lastly, *verified synesthetes* both stated that they experienced a spatial form *and* performed significantly better than controls (Z-scores greater than 1.96).

In Study 1 we examined spatial representations for the months of the year as drawn by the three groups described above. One goal of this study was to gain a better understanding of the phenomenology of synesthetic calendar forms, and the frequency of different shapes. The second goal was to assess whether non-synesthetes, who do not spontaneously associate months with particular locations in space, would produce relatively consistent (non-random) patterns when asked to draw the year in a spatial arrangement, and to compare the calendars drawn by non-synesthetes to those drawn by both potential and verified time–space synesthetes.

2.1. Methods

2.1.1. Participants

Individuals (183) recruited from the cognitive science and psychology subject pool participated for course credit. Seventy five participants were male, age ranged from 18 to 30 years.

2.1.2. Apparatus and procedure

Data was collected via the Internet with a customized Flash program,[1] which presented all instructions and stimuli. On the first screen participants were asked, ‘‘When imagining a yearly calendar (12 months), is there a specific shape that you see the months travel along?” Answer possibilities were ‘‘yes” or ‘‘no”. The program then prompted participants to visualize the months of the year as they imagined them and to place each month accordingly on the screen with a mouse-click. Each click of the

[1] The software (programmed in Flash) is freely available upon request from dbrang@ucsd.edu.

mouse left a small circular dot representing a particular month on the screen. For example, the first mouse-click left a dot labeled January; the second, February. The dots could then be moved around until the participant decided that the calendar looked accurate, and that he or she was ready to move onto the test phase.

During the test phase, participants were instructed to place each of the 12 months in the location they had originally chosen. On each trial, a prompt such as "Place November" was presented in the center of the screen, along with a cue month, that is, a randomly selected month (dot) presented in its original location. The cue month was intended to serve as an anchor, and to help participants to create appropriately scaled calendars. Participants were prompted with one of the 12 randomly chosen month names until each month had been presented five times for a total of 60 trials. *X*/*Y* screen coordinates were recorded on each trial for data analysis.

To illustrate the task, Fig. 1 shows examples of three subjects' individual placements of the dots, as made visible by the flash program. These outputs show all six dots that a subject placed on the screen for each of the 12 months throughout the session. Fig. 1a and b shows the outputs of two controls who reported experiencing the year as a spatial sequence (potential synesthetes), Fig. 1c shows the output of a control participant who denied experiencing the year as a spatial sequence (a non-synesthete).

2.1.3. Analysis

Consistency was evaluated by calculating the number of placement errors during the testing phase. *Placement errors* were defined as test trials placed closer to an adjacent month's original *x*/*y* coordinates than to the original coordinates of the

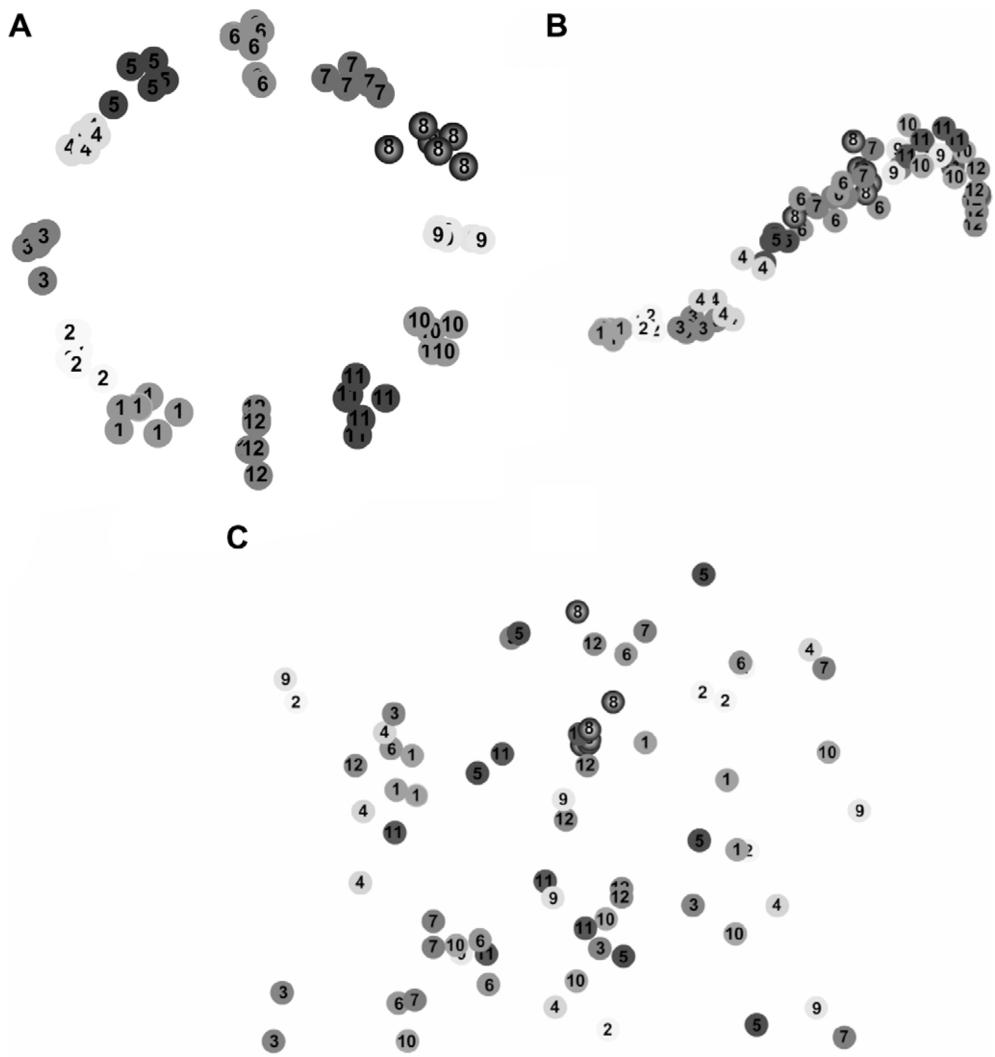

Fig. 1. Individual placements (original and subsequent test placements) by control subjects reporting a spatial sequence for months of the year (potential synesthetes; A and B) and a control subject who reported no spatial sequence (non-synesthete). Numbers represent a paired month (e.g. 1 = January, 2 = February, etc.).

prompted month. For example, an error was recorded if, when instructed to place 'March', the participant's placement was closer in *x*/*y* space to the original location of 'February' than to the original location of 'March'.

For the qualitative analysis, all six placements of each month were shown on a screen, with each month displayed in a different color. Two raters independently categorized each calendar into one of the following categories: circle (including ovals, ellipses or "bumpy" circles); rows or rectangle; straight line; curvy line; other shape; no discernable shape (seemingly random patterns of placements). The raters were both blind to the purpose of the study, and blind with respect to whether participants reported seeing the months of the year in a spatial array. Inter-rater agreement was 90.71% (88.24% for shapes drawn by control subjects; 93.51 for shapes drawn by potential (unverified) synesthetes; 100% for subjects who were subsequently verified as synesthetes).

2.2. Results

Out of 183 subjects, 81 subjects answered "yes" to the initial question of whether they perceived the months of the year in a spatial arrangement; 102 subjects answered "no". Thus, 44.26% of the participants reported that they perceived the months of the year as traveling along a specific shape. It is important to note, however, that this percentage represents those who report the perception of a spatial calendar, a standard which, without independent verification, does not merit the classification of these individuals as synesthetes.

Interestingly, though, if divided purely based on their self-report, we found that participants who reported seeing the year in a spatial arrangement produced fewer placement errors (M = 23.35, SD = 15.19) than those who denied seeing the year in a spatial arrangement (M = 27.88, SD = 14.02, $t(181)$ = 2.10, $p < .05$). However, among the 81 participants who reported a spatial calendar, only four showed consistency scores that were significantly higher than the control group's mean consistency (using a 1.96 Z score upper cut-off; see Fig. 2 for verified synesthetes' calendars). Our sample thus included 4/183 verified synesthetes, 77/183 potential synesthetes, and 102/183 non-synesthetes.

The different types of shapes produced by controls, potential synesthetes, and verified synesthetes are listed in Table 1, along with the number of participants in each group whose shapes were assigned to that type by both independent raters. As can be seen in Fig. 3, verified synesthetes were more likely than potential synesthetes to place the months in the shape of

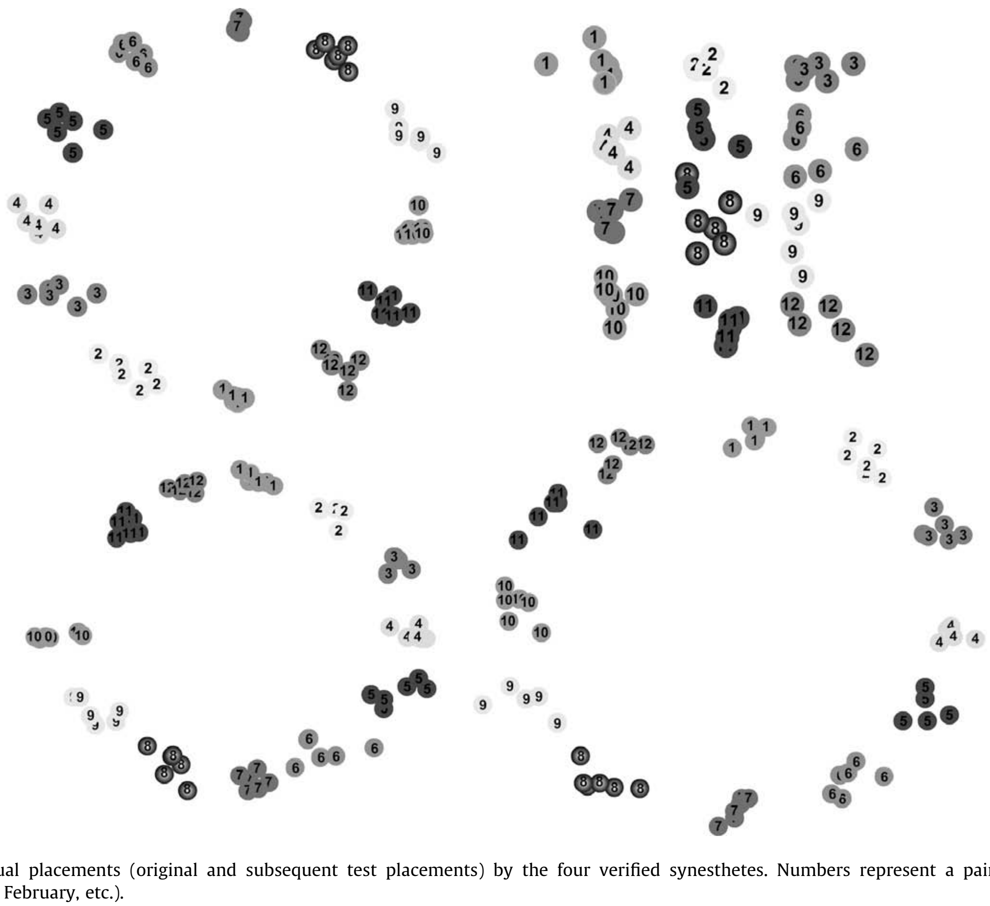

Fig. 2. Individual placements (original and subsequent test placements) by the four verified synesthetes. Numbers represent a paired month (e.g. 1 = January, 2 = February, etc.).

Table 1
Number of subjects drawing each type of calendar shape, as categorized by two raters for verified synesthetes, potential synesthetes, and non-synesthetes. Data is represented graphically in Fig. 3.

	Verified synesthetes	Potential synesthetes	Non-synesthetes	Total
Circle, oval or ellipse	3	19	11	33
Rows or rectangle	1	21	29	51
Straight line	0	17	26	43
Curvy line	0	5	12	17
Other shape	0	3	1	4
No shape discernable	0	7	11	18
Rater disagreement	0	5	12	17
Total	4	77	102	183

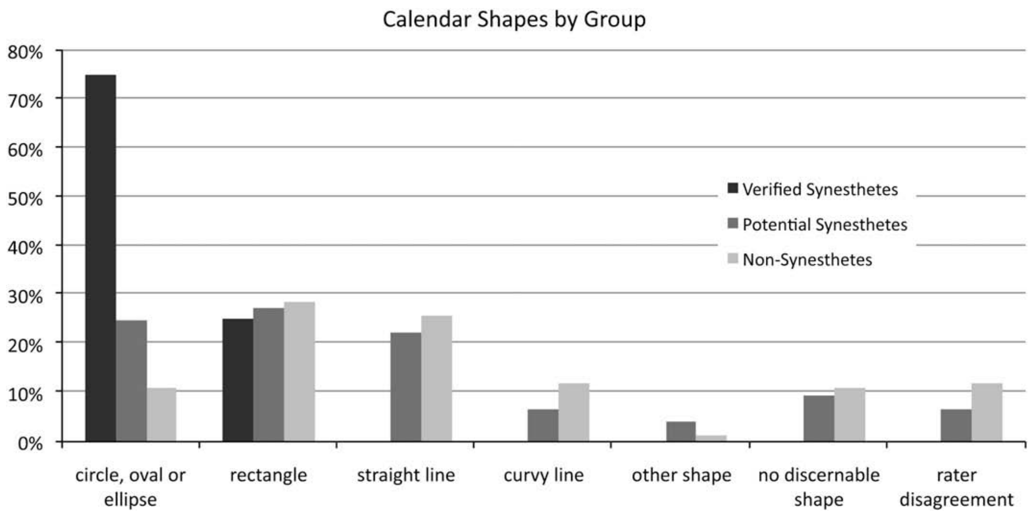

Fig. 3. Percentage of subjects drawing each type of calendar shape, as categorized by two raters.

circles, ovals or ellipses; chi-square (1) = 4.9, $p < 0.05$. Similarly, potential synesthetes in turn were more likely to place the months in circular shapes than non-synesthetes; chi-square (1) = 6.1, $p < 0.05$. No other group differences were significant (all chi-squares (1) < 2; $p \geqslant .15$).

For the majority of shapes, the *initial* months of the year were placed in a left-to-right direction. For example, participants tended to place February to the right of January. This was the case in verified synesthetes (left-to-right start in 3 out of 4 shapes; 75%), potential synesthetes (left-to-right start in 56 out of 73 shapes; 76.7%) and controls (left-to-right start in 77 out of 99 shapes; 77.8%).[2] Among circular shapes, including ovals, ellipses, and irregular "blobs", participants were overall more likely to draw clockwise than counter-clockwise calendars. Representative of this, all three verified synesthetes who experienced circular shapes reported clockwise orientations. Differing from verified synesthetes, 14 out of 19 potential synesthetes and 8 out of 11 non-synesthetes crafted clockwise shapes.

2.3. Discussion

Previous reports in the literature have estimated the frequency of sequence-space synesthesia between 5% and 17% (see Sagiv, Simner, Collins, Butterworth, & Ward, 2006 for a review). While more than 44% of our participants reported seeing the months of the year as forming a specific shape, our consistency test revealed only a small number (4) of these individuals to be more consistent than non-synesthetes for an overall prevalence of verified synesthetes being 2.2% of participants tested. Similarly, Simner and colleagues (Simner et al., 2006) found that only 1 in 5 potential grapheme-color synesthetes were more consistent than controls. Nevertheless, the frequency of verified time–space synesthesia in the present study (4 out of 83 self-reporters) is lower than that observed in previous counts, and may suggest our test of consistency is an especially conservative one.[3] Alternatively, this small proportion of verified synesthetes among potential synesthetes may simply reflect the question subjects were posed: "When imagining a yearly calendar (12 months), is there a specific shape that you see the months travel along?" This question does not make a distinction between whether subjects felt the shape was always present,

[2] For this and subsequent analyses, only discernable shapes that the raters agreed on were counted.
[3] Indeed, the 2.2% figure may represent a lower limit to the prevalence of the phenomenon.

or if they simply felt they could at that current point imagine a shape, perhaps never thinking about months of the year in that fashion before.

Accounting for some of this variability, many time–space synesthetes report forms that are three-dimensional and may not easily be projected onto a two-dimensional plane and placed on a screen in front of them, and differences exist between individuals in the level of awareness and attention is paid to their calendars in normal situations. Similarly, time–space synesthetes often state that each month encompasses a region of space, rather than a singular location, and some of our subjects complained that they found it difficult to translate a region of space to a specific point. Further, compared to remembering colors for each letter of the alphabet as controls for studies on grapheme-color synesthesia are required, the task of remembering the relative location of 12 months is relatively easy. Finally, the fact that spatial mappings for temporal sequences (such as calendars or clocks) are so prevalent in our culture and in our everyday planning and thinking about time, may facilitate the spontaneous association of time units with spatial locations. Interestingly, potential synesthetes as a group showed marginally greater consistency than non-synesthetes ($t(177) = 1.55$, $p = .06$ 1-tailed), raising the possibility that the potential synesthetes included a few 'true' synesthetes whose performance fell slightly below our verification criterion. Alternatively, this finding raises the intriguing possibility that potential synesthetes manifest a weaker variant of the condition.

Consistent with a graded view of sequence-form synesthesia, we found that even non-synesthetes, who denied seeing the months of the year in a spatial array, were able to place the dots in a non-random pattern on the display (see also Price & Mentzoni, 2008). Although they lacked the phenomenology of a spatial calendar, these participants apparently found the task to be interpretable – presumably because of conceptual mappings between the domains of time and space. The most commonly chosen shapes by non-synesthetes, i.e. those who denied seeing a spatial calendar, were rows or rectangles, and straight lines. Such choices presumably reflect cultural artifacts that employ time–space mappings, such as wall calendars and timelines. Some non-synesthetes nevertheless defined consistent circles, resembling those of our verified synesthetes, and in line with findings in grapheme-color synesthesia that control subjects tend to pick non-arbitrary letter/number–color associations, often matching those of synesthetes (Simner et al., 2005).

Verified synesthetes were most likely to place the months in a circular shape (including ovals and ellipses), while our two control groups were most likely to place the months of the year in rectangles. Thus, verified synesthetes' representations were more likely to be idiosyncratic (not a conventional calendar mapping) than those of the control groups. However, the influence of cultural standards is evident in all three groups, as the shapes predominantly involved a left–right direction, and clockwise, rather than counterclockwise orderings of the months. Similar to the graded results of consistency showing potential synesthetes (as a group) to be slightly more consistent than non-synesthetes, the creation of circular shapes was present in each of our three groups of participants in graded numbers (75% verified synesthetes, 24.7% potential synesthetes, 10.8% controls). This is especially intriguing given that the majority of descriptions of time–space synesthesia have focused on circular shapes, including the first reports by Galton.

3. Study 2

Study 2 compared the ability of synesthetes and non-synesthetes to memorize a novel spatial calendar and to consistently reproduce it. Given the prevalence of circular calendars among the verified synesthetes in Study 1, for Study 2 we recruited a group of time–space synesthetes who reported that they experienced the months of the year as traveling in a roughly circular shape. Further, because the within-session consistency metric used in Experiment 1 seemed somewhat conservative, in Study 2 we employed an alternate defining factor of synesthesia: consistency over time. Inclusion in this new group of synesthetes was thus dependent on two criteria: first, the subjective report of experiencing a spatial calendar that was circular in shape, and second, high cross-session consistency scores on the spatial placement task used in Study 1.

Previous studies have demonstrated that synesthetic percepts are not merely salient to the individual, but are also subject to interference effects when synesthetes are presented with incongruous associations (Nikolic, Lichti, & Singer, 2007; Sagiv et al., 2006). To test whether these same interference effects would extend to time–space synesthesia, we recruited a new group of synesthetes, separate from those described in Study 1, and assessed their consistency in recalling both their own spatial calendar, and one which was opposite in orientation from their own (e.g. a synesthete whose calendar travels clockwise might be expected to experience difficulty memorizing a counter-clockwise calendar). Synesthetes' performance on each of these calendars was then compared to a group of non-synesthetic controls' performance on the same calendars (each control yoked to a particular synesthete).

3.1. Methods

3.1.1. Participants

Eleven synesthetes and 48 control participants participated in Study 2 for course credit.

Synesthetes were included in Study 2 only if they reported a circular calendar shape (including ovals and ellipses) that they were able to project onto a two-dimensional plane. Synesthesia was verified by test–retest consistency on the month placement task described in Study 1, in which the second test was conducted an average of 4.5 months after the initial session. In the second session, synesthetes' placements were on average 7.4° of visual angle from their original placements (made approximately 4.5 months earlier).

The legitimacy of this latter consistency measure was assessed in a separate control study of 42 non-synesthetic control participants (none of whom participated in the present study) who were tested in a similar test–retest paradigm, an average of 1.9 months apart. Their designation as non-synesthetes was based on a "no" response to a query about whether they envision the months of the year in a particular shape. In the initial testing session of this control study, non-synesthetes were given a synesthetes' calendar to memorize, and were subsequently tested on the month placement task described in Study 1. In the second session, these participants were asked to place each of the 12 months of the year on the screen with the mouse, and were given the option of dragging each of the 12 dots to the remembered position. These 42 participants' second session placements were an average of 32.3° from their initial placements. Synesthetes' performance on this task was thus reliably better than that of controls ($t(51) = 2.85$, $p < .01$), validating their inclusion in Study 2.

Besides the 11 synesthetes, Study 2 also included 48 non-synesthetic control participants from the cognitive science and psychology pool who participated for course credit. Control participants all answered "no" to a query about whether they imagine the months of the year in a particular shape.

3.1.2. Apparatus and procedure

The materials and procedure were nearly identical to those in Study 1, such that synesthetes identified and were subsequently tested on the locations of months in their own spatial calendar. Synesthetes were also given another synesthete's calendar to memorize, and were then asked to perform the calendar testing phase for this additional sequence. These calendars were specifically chosen to be incongruent with each synesthete's experienced calendar. That is, synesthetes that perceived the months of the year in a clockwise array were asked to memorize a counter-clockwise calendar, while those that perceived the months of the year in a counter-clockwise array were asked to memorize a clockwise calendar. 6 out of the 11 synesthetes were tested on their own calendar first, followed by the incongruent calendar for counterbalancing purposes.

Each control participant was yoked to one of the 11 synesthetes, such that they were tested on the same "congruent" and "incongruent" calendars in the same order as their paired synesthete. As the synesthetes actively defined their own calendars by clicking a mouse at the correct location for each month, controls were shown each month's location on the screen with a small square, and were asked to place that month within the square; this served to ensure each subject had equal engagement with the computer during placement of the "congruent" calendars. For "incongruent" calendars, both synesthetes and controls alike were shown a calendar representation and instructed to memorize the location of each month to the best of their ability.

As in Study 1, the testing phase in Study 2 involved prompting participants with each of the 12 month names in five different random orders for a total of 60 trials. Besides the centrally presented month prompt (i.e. "Place October"), test trials included a month cue, that is, a randomly chosen month (e.g. "May") whose dot appeared in its original location. Month cues were intended to serve as perceptual anchors and to help participants to construct appropriately scaled calendars. Participants were prompted with each of the 12 month names in five different random orders for a total of 60 trials. *X*/*Y* coordinates were recorded on each trial for data analysis.

3.1.3. Consistency measure

Placement errors, as defined in Study 1, served as the critical consistency measure for Study 2.

3.2. Results

Repeated measures ANOVA comparing congruous to incongruous calendars between synesthetes and controls yielded significant main effects of group [$F(1, 57) = 12.70$, $p < .001$] and condition [$F(1, 57) = 6.96$, $p < .05$] and a significant interaction between group and condition [$F(1, 57) = 4.78$, $p < .05$; Fig 4]. Follow-up analyses showed synesthetes committed significantly fewer placement errors when tested on their own calendars (7.6 errors) compared to their performance on a learned calendar sequence in the opposite direction (15.2 errors) [$F(1, 10) = 12.36$, $p < .01$], consistent with findings of interference in other forms of synesthesia. Controls, however, did not reliably differ between congruous calendars (20.8 errors) and incongruous calendars (21.5 errors) [$F(1, 47) = 0.25$, $p = .62$] suggesting that the congruous and incongruous calendar sequences were comparable in difficulty. Further, comparison of control participants' performance on clockwise (21.4 errors) and counterclockwise (20.9 errors) calendars revealed no reliable differences [$F(1, 47) = 0.13$, $p = .73$]. Of additional interest, synesthetes' performance on a learned incongruous calendar was superior to that of non-synesthetic controls' performance on the same calendars $t(57) = 2.29$, $p < .05$).

As additional confirmation that synesthetes' placement of congruous compared to incongruous month locations was more accurate, we examined synesthetes' performance as a function of change (i.e. the number of errors on the first through third replacements). Owing to synesthetes' inherent sense of correctness for a month's location, we expected little improvement of performance across trials in response to congruent month locations, but a learning curve across trials in response to incongruous calendars. Accordingly, synesthetes' performance curve to congruous calendars was relatively flat (slope = .13) [one-sample *t*-test $t(10) = 0.54$, $p = .60$] demonstrating no learning across trials. However, synesthetes' performance curve to incongruous representations showed a strong negative slope (slope = −.73, where negative indicates fewer errors)

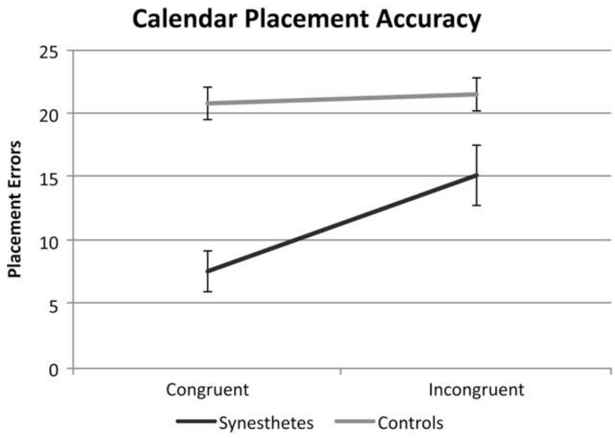

Fig. 4. Mean number of placement errors for synesthete's own spatial calendar versus a memorized calendar of opposite orientation, compared to controls' performance on the same calendars. Error bars represent standard error of the mean.

[one-sample *t*-test $t(10) = 2.67$, $p < .05$], revealing increased performance as the task continued. Additionally, a paired *t*-test revealed significant differences between congruous and incongruous calendar slopes $t(10) = 2.46$, $p < .05$.

3.3. Discussion

As expected, synesthetes were more consistent in their placement of months for their own calendar than they were for another synesthete's calendar arranged in the opposite direction (the additional sequence they were asked to memorize). Controls, however, showed no significant differences between the two calendar sequences, as both forms would have been perceived as incongruous. A second, and unexpected, finding of Study 2 was that synesthetes' performance on the additional sequence they were asked to memorize was superior to that of non-synesthetes' performance on the same calendars. This was the case in spite of the fact that synesthetes were tested on these additional sequences in the same session as they were tested on their own calendars, and, moreover, that these additional sequences were specifically designed to conflict with synesthetes' own calendars. These data point to the existence of generalized differences between synesthetes and controls in the ability to use mappings between ordered sequences and spatial locations.

4. General discussion

Overall, Study 1 revealed a substantial range of variability in our three groups (verified synesthetes, potential synesthetes, and non-synesthetes), as reflected in the variety of calendar forms chosen by each group (cf. Fig. 3). In fact, verified synesthetes were the least variable of our groups, in that 3 out of the 4 described spatial forms that were roughly circular. Given the small number of verified synesthetes in our sample, however, the generalizability of this finding is somewhat tenuous. Nonetheless, the prevalence of circular calendars in the present study is in keeping with the focus on circular forms in the extant literature on sequence-form synesthesia (Price & Mentzoni, 2008; Smilek et al., 2007). Interestingly, potential synesthetes, who reported spatial calendars but failed to meet our consistency criterion for synesthesia, produced fewer circular calendars than the verified synesthetes, but reliably *more* than did the other control group (non-synesthetes). The latter, who denied experiencing any associations between the months of the year and spatial forms, were most likely to produce rectangles and lines.

Focusing on synesthetes who report circular calendars, Study 2 compared the performance of a separate group of time–space synesthetes to non-synesthetes on a spatial cued recall task for a novel synesthetic calendar. Remarkably, the time–space synesthetes in Study 2 performed better than non-synesthete controls on this task – in spite of the fact that the novel calendars were chosen to be opposite in orientation from the synesthetes' own calendars. Synesthetes' better performance on the learned calendars suggests time–space synesthetes have an enhanced ability to learn mappings between ordered sequences and spatial forms, in keeping with the report by Simner and colleagues (Simner, Mayo, & Spiller, 2009) that time–space synesthetes perform superiorly to controls on tests of visual memory. This result is all the more interesting as incongruency paradigms in other forms of synesthesia have shown *reduced* performance in synesthetes compared to naïve controls. In grapheme-color synesthesia, for example, synesthetes were less accurate than controls to remember number–color associations that differed from their natural mappings (viz. controls were better able to remember 2 = green than a synesthete for whom 2 appears blue; Smilek, Dixon, Cudahy, & Merikle, 2002). Results of the present study may thus be unique to time–space synesthesia, and the mechanisms engaged.

4.1. Influence of cultural norms on synesthetes and controls

Apart from the group differences discussed above, the present study also reveals a surprising degree of similarities between verified synesthetes and controls. Control participants had little difficulty learning associations between months and spatial forms, and actually performed quite well on the consistency tests administered to synesthetes. Interestingly, Study 1 revealed that nearly 75% of participants (Verified Synesthetes, potential synesthetes, and non-synesthetes in equal proportions) created representations placing February to the right of January. This left-to-right bias was constant even for the creation of unconventional shapes and counter-clockwise orientations, and may reflect similar mechanisms underlying left-to-right biases in the SNARC effect (Ishihara, Keller, Rossetti, & Prinz, 2008; Bächtold, Baumüller, & Brugger, 1998; but cf. Price & Mentzoni, 2008).

Whereas previous research has focused on biases in response selection and execution, the present study addressed biases in people's ability to learn and remember mappings between ordered sequences and spatial arrays. Moreover, whereas previous research has tended to explore one-dimensional spatial forms, the present study also addressed biases in mappings between ordered sequences and two-dimensional shapes. Given that many time–space synesthetes perceive their calendar to be three-dimensional, it presents the need to explore whether neurotypical individuals have biases in learning mappings between ordered sequences and three-dimensional forms.

4.2. Against a dichotomy between synesthetes and non-synesthetes

The distinction between synesthetes and non-synesthetes seems to be particularly challenging for time–space synesthesia, due in part to the apparent similarity between synesthetic sequence-form mappings and the conventional sequence-form mappings underlying many linguistic expressions and cultural artifacts. Study 1 showed an increasing tendency to portray the months of the year as a circular sequence from non-synesthetes to potential synesthetes to verified synesthetes, as well as a similar increase in consistency scores across these groups. Moreover, all three groups in Study 1 showed a preference for the production of left-to-right and clockwise ordering scheme. Results thus highlight the continuum between sequence-space mappings in synesthesia and in the general population and point to a need for more intermediate categories between verified synesthete and non-synesthete.

Further, our finding in Study 2 that time–space synesthetes performed better than non-synesthetes in learning novel calendars is suggestive of differences in the visuo-spatial memory abilities of the two groups. Indeed, these differences may underlie the emergence of time–space synesthesia, as people with a greater capacity to learn mappings between arbitrary spatial forms and temporal sequences might be more likely to think of the months of the year in terms of the idiosyncratic shapes described since the time of Galton, while those with less skill might be more reliant on culturally established mapping schemes.

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