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Handedness and calendar orientations in time–space synaesthesia

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In one common variant of time–space synaesthesia, individuals report the consistent experience of months bound to a spatial arrangement, commonly described as a circle extending outside of the body. Whereas the layout of these calendars has previously been thought to be relatively random and to differ greatly between synaesthetes, Study 1 provides the first evidence suggesting one critical aspect of these calendars is mediated by handedness: clockwise versus counter-clockwise orientation. A study of 34 time–space synaesthetes revealed a strong association between handedness and the orientation of circular calendars. That is, left-handed time–space synaesthetes tended to report counter-clockwise arrangements and right-handed synaesthetes clockwise. Study 2 tested whether a similar bias was present in non-synaesthetes whose task was to memorize and recall the spatial configuration of a clockwise and counter-clockwise calendar. Non-synaesthetes' relative performance on these two sorts of calendars was significantly correlated with their handedness scores in a pattern similar to synaesthetes. Specifically, left-handed controls performed better on counter-clockwise calendars compared to clockwise, and right-handed controls on clockwise over counter-clockwise. We suggest that the implicit biases seen in controls are mediated by similar mechanisms as in synaesthesia, highlighting the graded nature of synaesthetic associations.

Synaesthesia is a neurological condition that results in altered perceptual experience due to involuntary associations between particular processing streams, sensory modalities, or conceptual structures. In one common variant known as time–space synaesthesia, time units are understood spatially, such that months of the year embody highly consistent and memorable sequential paths (Smilek, Callejas, Dixon, & Merikle, 2007). Some synaesthetes report these spatial calendars are perceptually 'real' and occupy regions of

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space outside of their body (Brang, Teuscher, Ramachandran, & Coulson, 2010). Time–space synaesthetes' 'calendars' can take a variety of forms ranging from simple lines and circles to elaborate three-dimensional landscapes. For one of our synaesthetes (not included in the present study), months of the year exist in a circular ring that extends around her body along the horizontal plane; according to her description the ring rotates throughout the year in a clockwise fashion, with future months located just out of view behind her. Additionally, time–space synaesthesia is related to and often co-occurs with number-form synaesthesia (Sagiv, Simner, Collins, Butterworth, & Ward, 2006).

While there can be significant variation in the orientation or location of months, many synaesthetes perceive the year in circular shapes, most commonly as an image inside their 'mind's eye' (Brang *et al.*, 2010; Eagleman, 2009). Indeed Brang *et al.* suggest the circular shape as a salient difference between synaesthetes and non-synaesthetic controls, as the latter, when required to attribute a spatial layout for the months of the year, frequently default to linear arrays or rectangles used in calendars. Interestingly, synaesthetes' circular calendars are typically organized in a clockwise fashion, as the progression from early months to later months is akin to the direction of a clock. However, while the preferred direction may mimic that of a clock, the spatial organization of the months on the circle differs from the pattern on a clock face (Eagleman, 2009). For example, January is no more likely to occur at the 12 or 1 o'clock position than it is to occur at any other position on the clock face.

While the underlying basis for these clockwise preferences has not been examined, research into the non-synaesthetic population has demonstrated consistent left to right preferences for numbers and months of the year, known as the spatial–numerical association of response codes (SNARC effect; Dehaene, Bossini, & Giraux, 1993; Price & Mentzoni, 2008). Explanations for the linear SNARC effect have suggested that as western cultures learn to read from the left to the right, an automatic association is engendered for small or earlier concepts with the left side of space and later concepts to the right (Gevers *et al.*, 2006). Further, an investigation of participants whose reading experience includes languages read from right to left or vertically has shown reversed and vertical SNARC effects, respectively (e.g., Dehaene *et al.*, 1993). However, while it has been suggested that time–space synaesthesia is an extended version of the linear SNARC effect (Eagleman, 2009; Price & Mentzoni, 2008), previous research has incompletely characterized a link between the two.

After interviewing several time–space synaesthetes earlier this year, we began to notice an interesting trend; synaesthetes who report counter-clockwise calendar representations are largely left handed. One synaesthete even asked if her calendar travelled in a counter-clockwise manner *because* she was left handed. In view of this catalyst, we examined the handedness of time–space synaesthetes we had previously tested, to establish whether the apparent association between being left handed and reporting a counter-clockwise calendar was real, or a simple coincidence. Here we describe two studies examining the relationship between mappings of month sequences onto space for both synaesthetes and controls, and critically, whether the groups share the same basic set of preferences and differ only as a function of the perceptual/conscious experience of synaesthesia.

EXPERIMENT 1: HANDEDNESS ASSESSMENTS AND PREFERRED ORIENTATIONS IN SYNAESTHETES AND CONTROLS

While it has been reported that approximately 75% of time–space synaesthetes' calendars travel clockwise (Brang *et al.*, 2010; Eagleman, 2009), subsequent explanations of why up to 25% of calendars occur in a counter-clockwise fashion has not been explored. To examine the issue, 34 synaesthetes who had previously participated in studies in our lab before completed handedness assessment questionnaires in addition to providing depictions of the months of the year. Similarly, in an effort to detect latent preferences in a group not experiencing synaesthesia, 20 non-synaesthetic control subjects completed handedness assessment questionnaires and were subsequently instructed to draw the months of the year in a circular representation.

Methods

Participants

Data were collected from 34 time–space synaesthetes and 20 non-synaesthetic controls. All participants were fluent English speakers, born in either the United States or a western European country, had normal or corrected-to-normal vision, and none had any history of psychiatric or neurological disorder. The 34 synaesthetes ranged in age from 18 to 55 (mean age = 28 years, $SD = 11.6$) and included 27 women. The 20 control subjects ranged in age from 18 to 29 (mean age = 22 years, $SD = 2.6$) and includedt 10 women.

Handedness was assessed via the Edinburgh Inventory (Oldfield, 1971), which yields a laterality quotient ranging from $+1$ (strongly right handed) to -1. Synaesthetes' handedness scores ranged from $-.77$ to $+1.00$ with a mean of $+.43$, suggesting the majority of synaesthetes were right handed. Similarly, controls' handedness scores ranged from -1.00 to $+1.00$ with a mean of $+.42$, suggesting the majority of controls displayed right-handed tendencies as well; laterality did not differ between the groups: $t(52) = .09$, $p = .93$. Self-reported handedness was also obtained from each subject, revealing 8 left-handed, 2 ambidextrous, and 24 right-handed synaesthetes, as well as 6 left-handed, 0 ambidextrous, and 14 right-handed controls. As subjects often over-estimate the presence of strong right handedness (Oldfield, 1971), we focus on individuals' laterality quotients but also present self-reported handedness where appropriate; the two ambidextrous subjects showed scores more typical of left-handed subjects and so were grouped with the other left-handed synaesthetes.

Synaesthetes were recruited from a larger database of time–space synaesthetes from a series of past studies within our lab examining the phenomenon. Synaesthetes reported either two-dimensional or three-dimensional circular calendars. Synaesthesia was confirmed by means of consistency testing over time either for the visual or descriptive depiction of synaesthetic calendars (minimum of 3 weeks between test and retest, mean 109.4 $\pm$ 50 days). Control participants were interviewed prior to inclusion in the study; any yes response to a series of questions describing spatial forms and spatial representations of calendars merited exclusion. All participants gave signed informed consent prior to the experiment and participated either for cash or in fulfillment of a course requirement.

Materials and procedure

Synaesthetes were instructed to draw their synaesthetic calendar to convey the spatial layout for the 12 months of the year, followed by the completion of survey questions

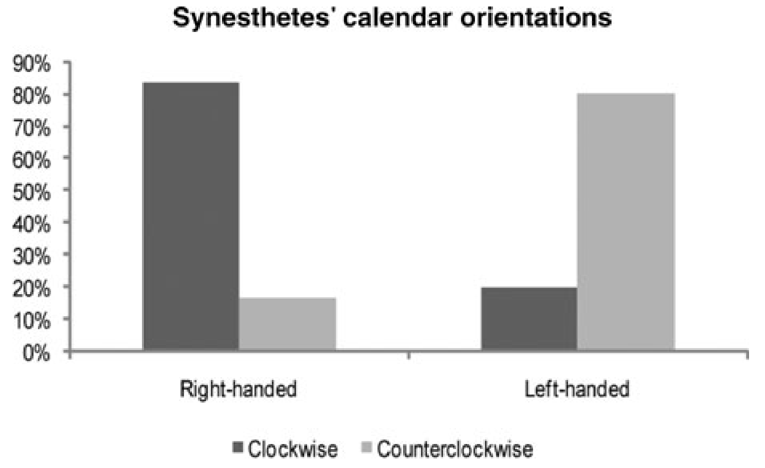

Figure 1. Preferred calendar orientations defined by synaesthetes, separated by handedness.

relating to their synaesthetic calendar. Similarly, control participants were instructed to 'Please write the name of each month (January–December) at the location along the circle that feels most natural. That is, imagine the months of the year travelled along a circle, please draw how you feel they would be arranged'. Drawings were subsequently scored for orientation and the location of the months along the circle.

Results

Of the 34 synaesthetes tested, 22 (65%) reported their calendar travelled clockwise compared to 12 (35%) who reported a counter-clockwise orientation. Using synaesthetes' self-report as a measure of handedness, 80% of the left-handers (including ambidextrous individuals) produced counter-clockwise calendars in comparison to only 17% of right-handers. The presence of orientation differences between left- and right-handed synaesthetes was confirmed via a 2×2 chi-squared analysis; chi-square $(1) = 12.40$, $p < .001$ (Figure 1). As handedness can be considered a graded phenomenon, this finding was additionally tested by comparing synaesthetes' handedness scores in terms of clockwise versus counter-clockwise calendar orientations. Results confirmed a stronger left-handed bias (mean $+.18$) for individuals with counter-clockwise calendars compared to clockwise (mean $+.56$, representing a stronger right-handed bias); results were confirmed using Student's *t*-test, $t(32) = 2.56$, $p < .05$. Differing from synaesthetes, all 20 control subjects produced clockwise orientations for their imagined calendars, regardless of handedness. On closer examination of the representations created by controls, the majority (16/20) placed January at the extreme top of the circle, three at the 1 o'clock position, and one at the 10 o'clock position.

Discussion

While time–space synaesthetes' calendars have previously been thought to be relatively random (Eagleman, 2009), here we provide the first logic to the underlying orientations.

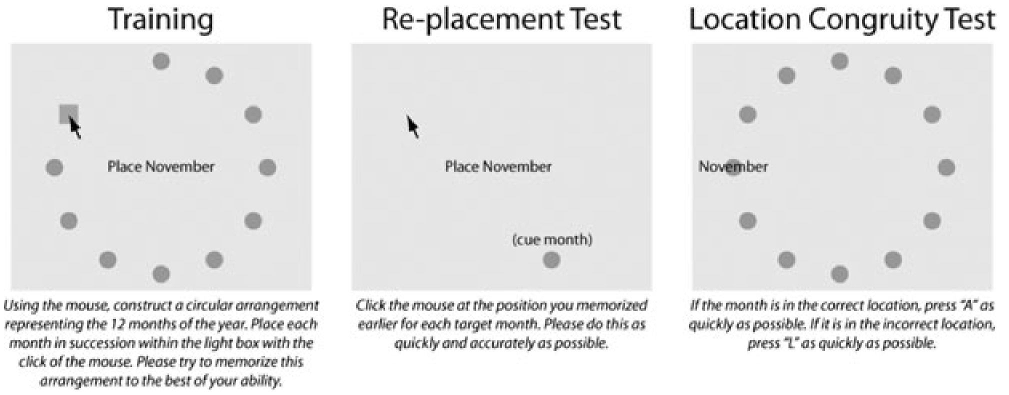

Figure 2. Layout of tasks in Study 2. Text at the bottom of the frame represents paraphrased instructions given to subjects. Training: subjects memorized the layout of a circular calendar, arranged either clockwise or counter-clockwise; January is represented by the topmost circular dot. Replacement test: subjects clicked the mouse at the remembered location for each month. Here the mouse cursor represents the correct location for November. Location congruity test: subjects responded whether each month was placed in a correct or incorrect location. Here November is shown in an incorrect location.

Study 1 suggests a statistically significant relationship between handedness and the sequential direction of circular calendars, with right-handed synaesthetes reporting mostly clockwise calendars and left-handed synaesthetes reporting mostly counter-clockwise. However, this was not the case for calendars drawn by non-synaesthetes, all of whom drew clockwise calendars, suggesting at least at a conscious level that months of the year have a clockwise bias for controls.

EXPERIMENT 2: IMPLICIT TESTS OF ORIENTATION BIAS IN NON-SYNAESTHETES

Study 1 demonstrated that when given the task of producing a spatial form to organize the months of the year, non-synaesthetic control participants were unanimous in their preference for a clockwise ordering of the months along a circle. However, given the prevalence of this ordering principle in western societies, this behaviour might merely reflect sensitivity to cultural biases. Accordingly, we hypothesized that if there was any counterpart to the synaesthetes' ordering preferences in the non-synaesthetic controls, it might be more apparent in an implicit performance measure than in an explicit ordering task.

In Study 2, we recruited a subset of the control subjects from the initial study to participate in two tests to assess implicit preferences for clockwise versus counter-clockwise calendar orientations (Figure 2). Subjects were instructed to memorize and recall clockwise and counter-clockwise circular calendar sequences, such that each subject completed the test twice; order was counterbalanced across subjects. In order to examine effects of calendar orientation while minimizing other elements, *both* calendars began with January in the same position (12 o'clock if viewed as a clock face) and were otherwise mirror reversals of one another: February at the 1 o'clock position for the clockwise orientation and at 11 o'clock for the counter-clockwise orientation.

Subjects' recall of these memorized calendars was tested via the replacement paradigm described by Brang *et al.* (2010), as well as a more fine-grained congruity test using reaction times. During the replacement test, subjects were prompted centrally with a month name and instructed to click their mouse in the correct location reflecting the memorized position of the month. In the congruity test, participants were instructed to judge whether a month (represented by the name of the month) appeared in the correct or incorrect location along a spatial arrangement.

If subjects' recall of clockwise and counter-clockwise orientations occurs through simple rote memory or perceptual learning, then there should be no differences between these spatial orientations. However, if implicit biases do exist for ordering months of the year along circular shapes, we should expect non-synaesthetes to exhibit reliably different performance on clockwise and counter-clockwise calendars.

Methods

Participants

Fifteen of the non-synaesthetic individuals from Experiment 1 were enrolled in Study 2, including non-synaesthetic subjects ranging in age from 18 to 25 (mean age = 22 years, $SD = 2.2$) and nine women. The majority of our participants were right handed: 10 right, 5 left, laterality quotient $+.41$.

Materials and procedure

The materials and procedure were similar to those in Brang *et al.* (2010). Non-synaesthetes were shown one of two mirror-image spatial calendar configurations (one clockwise and one counter-clockwise), were instructed to memorize this arrangement, and were subsequently tested on this sequence using a replacement consistency measure and a location congruity test. After completion of the location congruity test, subjects were given the second spatial calendar configuration for memorization and testing. Order of the calendars selected was randomized between participants and orders did not differ as a function of handedness, $t(13) = 0.88, p = .40$.

January originated at the top of the circle for both calendars and February was placed 30° in either a clockwise or a counter-clockwise direction along the circle. Subjects were shown each month's location on the screen with a small square and were asked to click inside that square to place the corresponding month. Each click of the mouse left a small circular dot representing a particular month on the screen. For example, the first mouse click left a dot labelled January; the second, February.

After the placement phase each subject was tested on their replacement accuracy as well as a location congruity test for the months. In the replacement test (as in Brang *et al.*, 2010), 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 centre 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.

In the location congruity test, the initial 12 blue dots from the placement phase were shown on the screen and each month name was presented in either the congruent location (50% of trials) or an incongruent location: either 1 month away (March in the February/April position; 25% of trials) or 2 months away (March in the January/May position; 25% of trials). Each month name was presented six times for a total of 60 trials. Subjects were instructed to press the 'L' key if the month name was in the correct location and the 'A' key if in the incorrect location. Subjects were instructed to respond as quickly and accurately as possible. Accuracy and reaction times were recorded for subsequent analysis.

Results

Results were examined with a repeated measures ANOVA comparing factor of orientation (clockwise/counter-clockwise) in both tests of replacement and congruity. Non-synaesthetes showed no effects of orientation as a group in either the number of placement errors made in the replacement test [$F(1,14) = 0.30$, $p = .59$] or in their accuracy in the congruity test [$F(1,14) = 0.05$, $p = .83$]. In order to examine non-synaesthetes performance as a function of handedness, a linear regression was conducted comparing subjects' handedness scores against difference scores between the two tasks (replacement: number of counter-clockwise replacement errors minus clockwise; congruity: counter-clockwise accuracy minus clockwise). Linear regression revealed that handedness significantly predicted performance in these tasks [$F(2,14) = 5.44$, $p < .05$]. Follow-up analyses showed a non-significant correlation between handedness and placement errors in the replacement test [$R = .17$, $t(13) = 0.63$, $p = .54$] and a strong correlation between subjects' handedness accuracy on counter-clockwise relative to clockwise calendars in the congruity test; $R = .67$, $t(13) = 3.29$, $p < .01$ (Figure 3). That is, subjects possessing an increased number of left-handed traits performed better on counter-clockwise calendars and worse on clockwise calendars. This bias was also seen as a non-significant trend in the congruity test reaction time data, such that subjects showing an increased number of left-hander traits responded more quickly to targets on counter-clockwise compared to clockwise calendars; $R = -.33$, $t(13) = -1.27, p = .23$.

Discussion

Study 2 demonstrated that handedness significantly predicted performance on clockwise compared to counter-clockwise calendars in non-synaesthetes. Brang *et al.*, (2010) reported that synaesthetes made significantly fewer placement errors on their own synaesthetic calendars compared to incongruous calendars, as assessed by the same replacement task used here. Accordingly, this pattern of results suggests that left-handed non-synaesthetes have an implicit bias for counter-clockwise calendars while right-handed individuals show the opposite pattern; interestingly, this runs counter to the subjective preference for clockwise calendars seen in non-synaesthetes regardless of handedness (Study 1). This pattern of results differs from left-right preferences revealed by the SNARC effect as the latter has been shown to be similar in left- and right-handed individuals (Dehaene *et al.*, 1993). However, it remains to be seen if the present findings reflect a relationship to cultural and physiological underpinnings of the linear SNARC.

GENERAL DISCUSSION

Non-synaesthetes memorized and were subsequently tested on the locations for two circular spatial sequences that differed only in orientation (clockwise vs. counter-clockwise). Performance on clockwise relative to counter-clockwise mappings was correlated with handedness, such that right-handed subjects performed better on clockwise and left-handed subjects performed better on counter-clockwise mappings. This pattern of results is consistent with similar subjective reports by synaesthetes (Study 1), but interestingly conflicts with the same reports from non-synaesthetes. Superficially, this may seem like a counter-intuitive finding in that conventional sequences like clocks travel in clockwise patterns. However, even though research has suggested that non-synaesthetes (Study 1) as well as the majority of synaesthetes (Brang *et al.*, 2010; Eagleman, 2009) prefer clockwise orientations, suggestive of inherent clockwise representations, the locations of the months do not follow the mapping of a clock. Specifically, Eagleman (2009) has shown that the location of January for a particular synaesthete is equally likely to occur at any location on the circle, and is by no means more common at what would be considered the 1 o'clock position. Along similar lines, the subjective drawings by the controls in Experiment 1 showed the majority of participants placed January at the very top of the circle, at what would be the 12 o'clock location. If controls were mapping these calendars onto the face of a clock, then the logical starting location for January would be slight shifted to the right with December at the extreme top of the circle, suggesting that the clockwise preference in synaesthetes and controls may have less to do with cultural conventions and clocks and more to do with inherent biases.

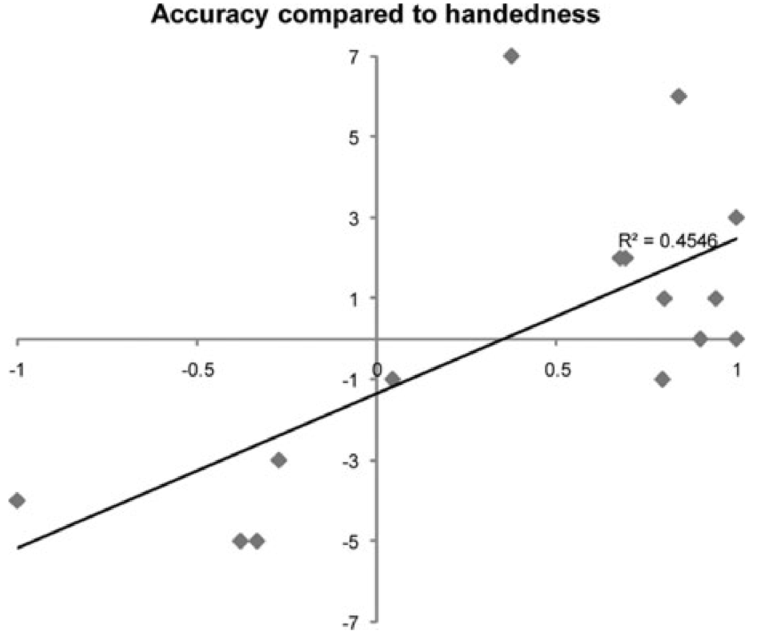

Figure 3. Correlation between handedness and performance bias in controls for counter-clockwise versus clockwise calendars. *X*-axis shows subjects' handedness scores; −1 strongly left handed, +1 strongly right handed. *Y*-axis shows the difference scores from the number of counter-clockwise–clockwise errors.

In terms of the neural basis of this effect, research investigating conceptual sequences in the normal population have highlighted the involvement of parietal regions (e.g., Dehaene, Piazza, Pinel, & Cohen, 2003; Pesenti, Thioux, Seron, & De Volder, 2000). Of particular interest is the strong lateralization of the neural mechanisms present in spatial processing. One clinical condition known as hemineglect is marked by patients' inability to attend to the left side of the world, including the left side of the body and object-specific space (Critchley, 1953). While often a transient condition, hemineglect commonly occurs after damage to the right parietal lobe, providing a strong suggestion that lateralized mechanisms in the parietal lobe are involved in spatial processing. Further, as handedness is frequently mediated by hemispheric dominance or lateralized processes the present effects may result from subtle lateralized biases in the mechanisms underlying spatial processing. A simple test to confirm this could be gained through correlating subjects' performance on this task with a strictly spatial task where effects of laterality are measured (e.g., the number bi-section task; Zorzi, Priftis, & Umiltà, 2002).

An additional possibility as to why this pattern of results has emerged could be due to a form of embodied cognition relating to the types of preferred movements and actions engendered by use of the right hand compared to the left. This suggestion receives partial support from an ambidextrous time–space synaesthete who serendipitously contacted us after this study had been completed. This individual reported that after a concussion the movement of her calendar changed depending on the hand she was using during a particular task. Specifically, using her left hand caused her calendar to organize in a counter-clockwise fashion compared to a clockwise pattern when using her right hand; she found this reorganization of her calendar frustrating and jarring. Admittedly, it remains unclear why one hand would have orientation-preferred movements, without invoking the possibility that the muscles in the wrist permit more fluid movements in a medial to lateral orientation. However, while individuals do tend to create mirror symmetrical as opposed to identical movements between the hands (Semjen, Summers, & Cattaert, 1995), studies have tended to find that young children and adults alike draw circles in a clockwise manner regardless of handedness (see Scheirs, 1990 for a review). While the current results cannot disambiguate these or other possibilities, we suggest these an avenue for future research.

The present study provides an interesting intersect between synaesthesia and the normal population. In Study 1, control subjects as a whole reported a preference for clockwise calendar orientations, differing from the mixed responses seen in synaesthetes. However, as shown in Study 2, non-synaesthetic controls' subjective reports corresponded poorly to their performance on the location congruity task. Study 2 revealed better performance on counter-clockwise sequences in left-handed control subjects and a corresponding advantage on clockwise sequences in right-handers. In both synaesthetes and controls then, calendar orientations were similarly associated with handedness. These data support the suggestion that time–space synaesthesia is an extension of the normal cognitive mechanisms present in all individuals (Mann, Korzenko, Carriere, & Dixon, 2009), in line with other findings of synaesthesia as an exaggeration of normal cognitive processing (Cohen-Kadosh & Henik, 2007; Sagiv & Ward, 2006). Indeed, the main difference between synaesthetes and non-synaesthetic controls may lie in the subjective experience of synaesthesia. This in turn may relate to the fact that spatial form synaesthetes (including time–space synaesthetes) show enhanced visual imagery (Price, 2009), possibly allowing synaesthetes to access intrinsic preferences we all share.

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