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# A different outlook on time: Visual and auditory month names elicit different mental vantage points for a time-space synaesthete

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ABSTRACT

Synaesthesia is a fascinating condition whereby individuals report extraordinary experiences when presented with ordinary stimuli. Here we examined an individual (L) who experiences time units (i.e., months of the year and hours of the day) as occupying specific spatial locations (January is 30° to the left of midline). This form of time-space synaesthesia has been recently investigated by Smilek et al. (2007) who demonstrated that synaesthetic time-space associations are highly consistent, occur regardless of intention, and can direct spatial attention. We extended this work by showing that for the synaesthete L, her time-space vantage point changes depending on whether the time units are seen or heard. For example, when L sees the word JANUARY, she reports experiencing January on her left side, however when she *hears* the word ''January'' she experiences the month on her right side. L's subjective reports were validated using a spatial cueing paradigm. The names of months were centrally presented followed by targets on the left or right. L was faster at detecting targets in validly cued locations relative to invalidly cued locations both for visually presented cues (January orients attention to the left) and for aurally presented cues (January orients attention to the right). We replicated this difference in visual and aural cueing effects using hour of the day. Our findings support previous research showing that time-space synaesthesia can bias visual spatial attention, and further suggest that for this synaesthete, time-space associations differ depending on whether they are visually or aurally induced.



## 1. Introduction

Francis Galton (1880, 1881) reported that some individuals appear to visualize numbers in space, such that each number occupies a highly specific spatial location. He called these unusual spatial representations 'number forms'. Since then, researchers have identified other concepts such as time units that certain individuals mentally allocate to specific spatial locations (Seymour, 1980; Smilek et al., 2007). These individuals have reported experiencing the months of the year, days

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of the week and hours of the day as occupying highly consistent spatial locations relative to their own body (Duffy, 2001; Smilek et al., 2007). Typically, these spatial representations are ordered and fixed, and are used to organize events and appointments (Duffy, 2001; Smilek et al., 2007). This propensity to allocate units of time to specific spatial locations has been referred to as time-space synaesthesia (after Smilek et al., 2007).

There is debate as to whether this condition is truly a form of synaesthesia. After all, if requested to assign spatial locations to hours of the day, many non-synaesthetes would align the hours according to the traditional clock face. Unlike the clock face however, the time-space associations observed in synaesthesia tend to be much more elaborate, idiosyncratic and vivid than those found in non-synaesthetes. For instance, one synaesthete (H) described her time-space experience as the following, ''When someone mentions a year, I see the oval with myself at the very bottom, Christmas day to be precise. As soon as a month is given, I see exactly where that month is on the oval. As I move through the year, I am very aware of my place on the oval at that current time, and the direction I am moving in. For example, now I am moving upwards, in a north-westerly direction. It is always anti-clockwise''.

The linkage of time to space shares many of the defining characteristics of other forms of synaesthesia (e.g., grapheme-colour; see Sagiv et al., 2006 for a parallel argument regarding number-form synaesthesia). The time-space mappings are consistent over time and appear to be experienced involuntarily (Smilek et al., 2007). To assess consistency Smilek et al. (2007) used a laser pointer mounted on a 360° compass. Synaesthetes were asked to align the laser pointer through the center of each month and the compass angle was recorded. Synaesthetes were significantly more consistent at pointing to their month locations across repeated testing sessions than control participants. To assess the involuntary nature of time-space synaesthesia Smilek et al. used a spatial cueing task. Four time-space synaesthetes were presented months of the year (e.g., APRIL) in the center of a computer screen, followed by a target square presented either to the left or the right of the month name. On half of the trials the target appeared on the side of space corresponding to the month's synaesthetic location (e.g., if April was perceived by the synaesthete as being on the left, then the word APRIL was followed by a target on the left); on the other half of the trials the target appeared on the side opposite to the month's synaesthetic location (e.g., APRIL followed by a target on the right). The authors predicted that if the month names could trigger shifts of visual attention to their synaesthetically associated spatial locations, then the synaesthetes would be quicker at detecting targets that fell in the synaesthetically cued location versus the invalid location on the opposite side of space. Smilek et al. (2007) found that three of the four synaesthetes showed significant synaesthetic cueing effects. Because these cueing effects occurred even though the months were not actually ''predictive'' of the target location (i.e., on half the trials they cued the wrong location), and because the cueing effects occurred even when the target appeared very shortly (150 msec) after the onset of the month name (presumably before any strategy could be adopted), Smilek et al. concluded that, at least for some synaesthetes, time units were capable of involuntarily directing synaesthetes' attention to locations in space.

Here we examine an individual (L) whose time-space synaesthesia has features that are common to other time-space synaesthetes described in the literature thus far, but one salient feature that is to our knowledge unique. Like other time-space synaesthetes, L reports experiencing the hours of the day and months of the year as being represented in her egocentric space. She represents the months of the year arranged in the form of a giant ''scoreboard 7'' (see Fig. 1A for a ''bird's eye'' view of what her mental calendar looks like). When presented visually with month names, L reports that her mental vantage point is standing in the crux of the 7, looking directly ahead at April. Thus from this vantage point, she experiences January, February and March on her left, and May and June on her right. July to December form the tail of the 7 that runs along her right side from directly beside her to well behind her for the later months of the year. From her vantage point at the crux of the 7, the arm and tail of the 7 extend approximately one meter around her midline in egocentric space. The unique aspect of L's time-space synaesthesia is that when L *hears or thinks about* the names of the months of the year, her 7-shaped space does not alter, but her mental vantage point within this space changes. Relative to her vantage point when she sees month names (from the crux of the 7), for heard months it is as though she had walked around the top of the 7 to the other side of April (See Fig. 1A). Thus, from this mental vantage point she now experiences January, February and March on her right and May, June and July on her left. The subsequent months are on her left extending out into distal space. This change in vantage point is also apparent when L sees versus hears the hours of the day (Fig. 1B).

To objectively verify L's unusual subjective reports, we used the same spatial cueing paradigm as Smilek et al. (2007). Visual month names were centrally presented followed by

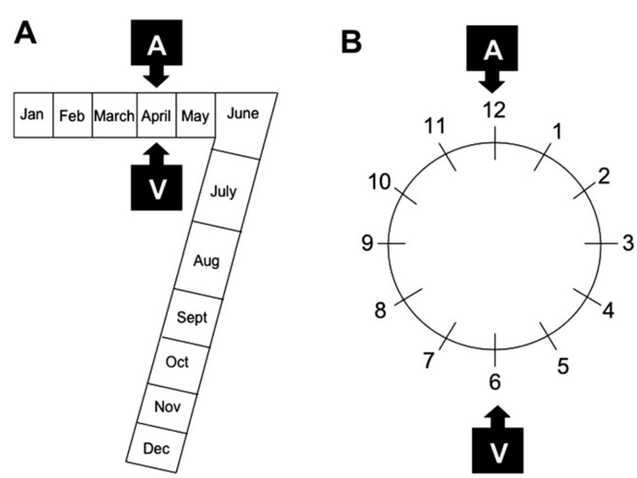


**Fig. 1 – Bird's-eye view of L's spatial organization of months of the year (Experiment 1) and hours of the day (Experiment 2). As illustrated, her representations of the months form the shape of a 'scoreboard 7' (A) and her hours take the form of a 'clock face' (B).**

a target square to the left or right of the month cue. We predicted that if the visually presented month name can trigger shifts of L's visual attention to its synaesthetically associated spatial location, then L should be quicker at detecting targets that fall in the synaesthetically cued (or valid) location versus the opposite (invalid) side of space. For instance, she should be faster to detect the targets on the left side of the display when cued by the early months of January, February, and March, because her synaesthetic experience would orient her attention to her left side of space. Crucially, if it is also true that L's vantage point changes when she *hears* the months instead of sees them, then aurally presenting those same early months that visually cued her to her left side of space should now orient her attention to her right side of space (hence right targets should be detected faster than left targets). Statistically, if the visual and aural inducers lead to different mental vantage points we should find an interaction between the type of inducer (visual and aural), the month cues (early months *vs* later months) and side of target (left and right). Of course, we predict that only the synaesthete will show this triple interaction – non-synaesthetes tested under the same experimental regimen will not show any cueing effects related to the month names.

## 2. Experiment 1 (months)

### 2.1. Methods

#### 2.1.1. Participants

A healthy 21-year-old female with time-space synaesthesia (L) and ten naïve non-synaesthetic controls (two males, $M = 24.4$ years old) volunteered to participate in this study for an honorarium. The controls were fully debriefed at study completion regarding the characteristics and different forms of synaesthesia, at which time the participants were asked if they experienced any such associations. None of the participants reported any form of time-space associations and were surprised to learn of the phenomenon. When the synaesthete (L) initially reported her vivid time-space associations, she was tested for consistency using the same method as Smilek et al. (2007). We used a laser level situated at her midline that measured 0°. The experimenter randomly asked her to point the laser level to the location of each month and the degree of angle was recorded (0°–360°), returning to 0° after each trial. The process was then repeated in a different location to make certain that landmarks in the room (e.g., a mark on the wall) could not be used as reference points. We then computed the standard deviation (SD) associated with each month and averaged them together to get an overall variability score (Smilek et al., 2007). L showed high test-retest consistency for each month, with an average deviation of less than 4.75°. This low variability for L is directly comparable to the consistency values in Smilek et al. who showed average variability scores of 4° for the synaesthetes PD and ST and 14° for twelve non-synaesthetic controls. Thus, L's highly consistent performance falls within the range of synaesthetes in Smilek et al. and outside the range of controls, confirming that the spatial forms she experienced were indeed reliable over time. Finally, all participants had normal or corrected-to-normal vision and hearing, were right-handed, and reported no reading or language difficulties. The University of Waterloo Office of Research Ethics approved all procedures and participants gave written consent before participating.

#### 2.1.2. Materials

We adopted the same spatial cueing task as that used by Smilek et al. (2007). All stimuli were presented on a 17" cathode ray tube (CRT) computer monitor in black on a white background. The fixation cross subtended .6° of visual angle in all directions. There were six different month cues: three early months (*January*, *February*, *March*) and three later months (*May*, *June*, *July*). The visual month cues were written in black text (Geneva font, 72 pt. created in SuperLab 4.0), measuring .7° in height and maximally 6.5° in length – *February*. Targets were black squares (each side .6°) presented to the left or right of the cue. The targets were placed 10.5° in eccentricity from the center of fixation. The auditory month cues were the same month names broadcast over the computer speakers located on each side of the computer monitor facing the participant. A button-box was located on the table in front of the participant to collect the participants' responses. The stimuli were presented and response times (RTs) recorded using SuperLab 4.0 experimental software.

#### 2.1.3. Procedure

Participants were seated unrestrained at a distance of 57 cm in front of the computer monitor. Participants were asked to press a centrally located key on a button-box as quickly and accurately as possible with their right (dominant) hand once they detected the targets' presence. In the case where the target was absent (i.e., 'catch' trials), they were instructed to withhold their response and wait for the next trail. Participants were advised that the month cues were in no way related to the target location, and were thus non-predictive. For all participants the session involving the visual presentation of month names was presented first, followed by a session in which the month names were presented aurally. Trials began with a fixation cross for 680 msec, which was then replaced randomly by a month cue (either *January*, *February*, *March*, *May*, *June* or *July*). The month cue remained on screen for 600 msec, followed by a target square presented to the left or right of the cue for 3500 msec or until the participant responded. The auditory trials followed the same procedure as the visual trials except the month cues were broadcast over the computer speakers. The month cues were not statistically predictive of target locations since on half (50%) of the trials, the target was presented on the side of the display synaesthetically cued by the month name whereas on the other half (50%) of the trials the targets were presented on the opposite side (synaesthetically invalid trials). The separate visual and auditory cueing sessions each contained four blocks of 132 randomized trials (60 valid, 60 invalid and 12 catch trials). The 'catch' trials contained no target and were inserted to make sure that the participants were attending to the task as well as to discourage participants from making anticipatory responses. Sessions lasted about 30 min each, amounting to about an hour of testing in total.

### 2.2. Results and discussion

L made few errors on 'catch' trials (95% correct). Only those control participants who performed above 80% correct on the catch trials were included in the analysis. Two participants were excluded on this basis. RTs of each participant were submitted to an outlier analysis in which observations ±2.5 SDs were discarded. A total of 2.81% of trials were discarded for the synaesthete and an average of 5.04% for the controls. The remaining RTs of each participant were analyzed using separate 3-factor analyses of variances (ANOVAs) involving inducer type (visual or auditory), month cue (early *vs* later months), and target location (left and right). To control type-I error rates for multiple tests, we used a Bonferroni correction resulting in an alpha level of .005. As predicted, L showed a significant 3-way interaction between type of inducer, month cues and side of target, $F(1, 925) = 155.35$, $p < .0001$. Each control was analyzed separately and after the Bonferroni correction, for no control was this triple interaction significant ($F$-statistics of the controls ranged from .002 to 7.16. None of these $F$-values were associated with probabilities below our Bonferroni corrected alpha level of $p < .005$).

Planned comparisons revealed the source of the 3-way interaction for L. The means involved in these planned comparisons are connected by the black and grey lines in Fig. 2 (the bars around the means reflect the 95% confidence intervals). We predicted that for visual presentations early months would cue attention to the left. In support of this prediction, following the early month presentations, left targets ($M = 315$ msec) were detected faster than right targets ($M = 352$ msec) – see the positively sloped solid line in Fig. 2A. As well, we predicted that later months should cue attention to the right. Following the later month presentations, right targets ($M = 304$ msec) were detected faster than left targets ($M = 334$ msec) – see the negatively sloped dotted line in Fig. 2A. For aural cues (shown in Fig. 2B), we predicted the opposite pattern of cueing. Namely, early months should now cue attention to the right. Supporting our prediction, following early month presentations, right targets ($M = 282$ msec) were detected faster than left targets ($M = 328$ msec) – see the negatively sloped solid line in Fig. 2B. Likewise, we predicted that later months should now cue attention to the left. Following later months presentations, left targets were detected faster ($M = 291$ msec) than right targets ($M = 331$ msec), – see the positively sloped dotted line in Fig. 2B. For these planned comparisons all $t$ values >4.0, and all $p$ values <.0001.

On both valid and invalid trials, we believe that L's attention is *automatically* cued to her synaesthetic spatial location. As evidence, a recent extension of the current study (Dixon & Jarick, in preparation) patterned after Smilek et al. (2007), revealed that L's valid and invalid RT differences emerged not only at long stimulus onset asynchrony (SOAs) but also at short SOAs (150 msec) indicating the effects were due to the months automatically cueing her spatial attention. These automatic cueing effects even emerged when 85% of the trials cued her attention to an invalid location. In light of this new work, we view the present results as reflecting automatic cueing of L's spatial attention.

Fig. 3 shows the mean RTs of the control participants, with bars around the means reflecting the range of control performance. A 3-way analysis of variance on the group data of the controls revealed no significant main effects or interactions. As can be seen in Fig. 3, for both visual and auditory month presentations L's means (represented by the asterisks) lie within the range of control means for the synaesthetically valid trials, but outside of the range of control performance for synaesthetically invalid trials where her attention was cued to the incorrect location.

The fact that L's responses for validly cued trials lies within the range of controls' RTs was initially surprising. In fact, she is clearly slower than the average of controls for these validly cued targets – a finding that at first glance appears to run counter the contention that month names cue her attention to locations in space. Even on these valid trials, however, one must interpret her performance within the context of an experiment in which on 50% of the time the month names cue her attention to an invalid location. On invalid trials her attention is directed to the "wrong" location and she must disengage attention from the wrong location and move her attention towards the correct location of the target. While this moving of attention elevates RTs on invalid trials, it likely also

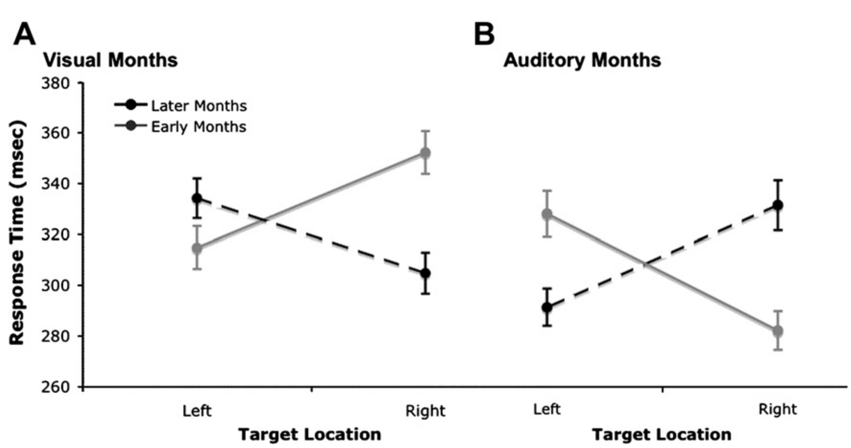


**Fig. 2 – Mean RTs of the synaesthete (L) for Experiment 1 (Months) across the two conditions: visual (Panel A) and auditory (Panel B). Note that the error bars represent the 95% confidence intervals around the mean.**

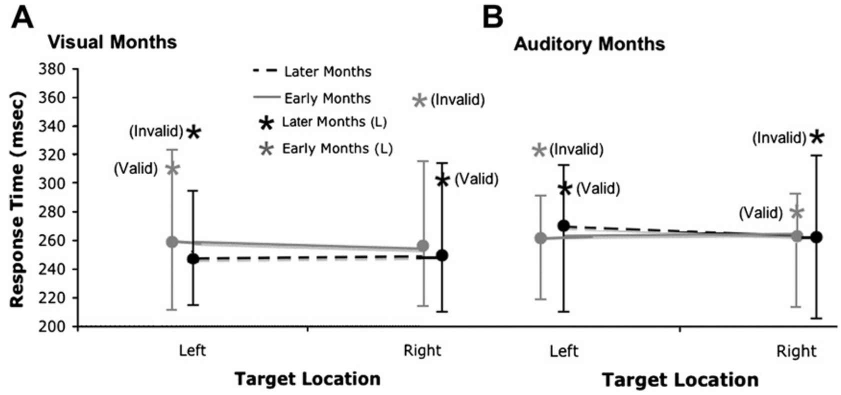


**Fig. 3 – Mean RTs of the Controls for Experiment 1 (Months) across the two inducer conditions: visual (Panel A) and auditory (Panel B). The error bars represent the 95% confidence intervals of participant means. The asterisks represent L's data, showing that her means fall inside the range of Controls during the valid trials (*valid* ), while she is an outlier during invalid trials (*invalid* ).**

impacts her RTs on valid trials – the fact that her attention is being cued to the wrong location on half of the trials would likely cause her to adopt a more cautious approach for completing the experiment (see Berteletti et al., in press for a similar argument).

This overall slowing effect has been shown in other studies of synaesthesia. In a study using the synaesthetic Stroop effect (e.g., Dixon et al., 2000; Dixon et al., 2004), Lupiáñez and Callejas (2006) showed that their synaesthete MA had overall longer response latencies compared to controls when naming the text colour or photism colour of a grapheme. Importantly, although on incongruent trials this effect was likely due to interference, an overall slowing effect also occurred on congruent trials (as in the current study). The Stroop literature also reveals that for non-synaesthetes congruent trial RTs become slower as the proportion of incongruent to congruent trials is elevated (Lowe and Mitterer, 1982; Bugg et al., 2008). For non-synaesthetes there are effectively no invalid trials (months never direct their attention to either the "right" or "wrong" side of space). The presence of many invalid trials may serve to elevate L's RTs to valid trials. Since there are no invalid (or valid) trials for non-synaesthetes, it may be easier for them to follow instructions and completely ignore the month cues to solely focus on the targets presented. If, as suggested by Smilek et al. (2007), month cues automatically cue attention in synaesthetes, it may prove more difficult for L to ignore these month cues. This splitting of her cognitive resources between processing the month cues and detecting the targets may serve to elevate both valid and invalid RTs. If so, then what is most important is not where the synaesthete falls relative to controls on valid and invalid trials, but rather the magnitude of the cueing effect.

Cue effect sizes are reflected by the difference between RTs in the invalid and valid conditions (Cueing effect = invalid RTs minus valid RT). To analyze these cueing effect sizes and to foster comparisons with other spatial cueing studies we compared the magnitudes of spatial cueing effects for each of the control observers as well as for L. The left side of Table 1 shows the RTs for valid and invalid trials and the magnitude of the cueing effect for visual month cues. For the visual month cues "valid" trials are valid from the synaesthete's perspective; early months followed by targets on the right and late months followed by targets on the left comprise valid trials (to estimate cueing effect sizes for controls one merely reverses the sign and looks for large negative cue effect sizes). For the auditory cues "valid" trials for both synaesthetes and controls involve early months followed by targets on the left, and later months followed by targets on the right. As can be seen in the table, the cueing effect sizes are much larger for the synaesthete L, than for any of the controls in both the visual and auditory presentations.

To directly compare L's cueing effect sizes to those of the control sample we used Crawford and Garthwaite's (2005) Revised Standardized Difference Test (RSDT). This test assesses whether the difference between L's RTs on valid and invalid trials is significantly larger than comparable differences obtained in our sample of non-synaesthetic controls. We assessed these differences for both visual and auditory cues, and applied the appropriate Bonferroni correction (alpha of $.01/2 = .005$). For the visual cues L showed significantly larger differences between valid and invalid RTs (cueing effects) than controls RSDT $t(7) = 5.00$, $p < .002$. She also showed larger cueing effects than controls with auditory cues RSDT $t(7) = 5.48$, $p < .001$.

Overall, the current findings in Experiment 1 are consistent with Smilek et al. (2007) who also used a cueing task and Price and Mentzoni (2008) who used the Spatial Numerical Association of Response Codes (SNARC) (non-cueing) task. Like Smilek et al., we showed strong synaesthetic cueing effects using visually presented month names. We also showed that aurally presented months names are capable of directing a synaesthete's attention to locations in space. Most importantly, we empirically validated L's description of having different mental vantage points depending on whether the she sees or hears month names. Both visually and aurally presented month names elicited strong cueing effects. Crucially, the exact same month names yielded opposite cueing effects depending on whether they were seen or heard.

**Table 1 – Experiment 1: (RTs) and SDs in msec for the synasethete L and each of the eight non-syneasthetic controls (C) for visual and auditory month cues. The cueing effects are denoted in bold and represent the difference in RT between the valid and invalid trials (invalid – valid). Note that the validity refers to whether the target was aligned (valid) or misaligned (invalid) with L's synaesthetic representation.**

| Inducer | Visual | | | | | Auditory | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Valid | | Invalid | | Cueing effect | Valid | | Invalid | | Cueing effect |
| | RT | (SD) | RT | (SD) | RT (In V-V) | RT | (SD) | RT | (SD) | RT (In V-V) |
| L | 309 | (46.2) | 343 | (45.5) | **34** | 286 | (41.6) | 329 | (52.5) | **43** |
| C1 | 273 | (38.3) | 278 | (43.9) | **5** | 287 | (43.5) | 293 | (55.1) | **6** |
| C2 | 285 | (46.2) | 280 | (39.3) | **−5** | 261 | (27.8) | 249 | (27.1) | **−12** |
| C3 | 316 | (75.2) | 303 | (72.1) | **−13** | 299 | (53.0) | 290 | (42.6) | **−9** |
| C4 | 239 | (40.2) | 243 | (42.8) | **4** | 281 | (51.3) | 272 | (46.5) | **−9** |
| C5 | 255 | (36.2) | 254 | (32.2) | **−1** | 284 | (70.0) | 278 | (57.6) | **−6** |
| C6 | 223 | (22.6) | 228 | (25.0) | **−4** | 213 | (22.3) | 213 | (23.7) | **0** |
| C7 | 222 | (25.3) | 222 | (19.9) | **0** | 224 | (18.6) | 223 | (20.1) | **−1** |
| C8 | 308 | (49.4) | 308 | (44.1) | **0** | 273 | (39.4) | 273 | (35.4) | **0** |

Furthermore, the lack of cueing effects found for control participants reflects the absence of a spatial representation for months of the year. This is consistent with a recent finding by Price and Mentzoni (2008), who demonstrated month-SNARC effects for synaesthetes, but not for the eighteen controls that participated.

## 3. Experiment 2 (hours)

The results from our first experiment clearly demonstrated that for L month names could direct her spatial attention and guide her behaviour. For this synaesthete, the months of the year are allocated spatial locations that form an atypical spatial form (akin to a scoreboard 7). L also allocates hours of the day to spatial locations. Unlike her 7-shaped mental calendar, her spatial form for hours of the day is far from atypical. In fact, she herself describes it as a standard "clock face". For non-synaesthetes, the clock face represents a convention of how we can translate time units into space in an agreed upon manner. Despite the familiarity of the clock face's time-space mappings, L's clock face differs from the standard clock face in a number of key ways. First, L's clock face is lying horizontally rather than standing upright – see Fig. 1B. Second, what is unique about her clock face is how vivid this representation is. Third, and most importantly for this study, is her propensity to view this clock face from different mental vantage points depending on whether she *sees* a time unit, or *hears* a time unit. Unlike for non-synaesthetes, for whom there is a canonical representation of a clock face (as though it is viewed from directly in front), for L seeing and hearing hour names leads her to view her clock face from completely different vantage points. Specifically, seeing the hours of the day (e.g., 3 A.M.) leads her to mentally view her clock face from a vantage point that is closest to the 6, farthest from the 12 (standard clock face), whereas hearing hours of the day (e.g., the spoken words "3 A.M.") leads her to mentally view her clock from the opposite vantage point (closest to the 12, farthest from the 6). In fact, she prefers to view her mental clock from this auditory vantage point (upside down), and uses it even when just thinking about the hours of the day.

The purpose of Experiment 2 is twofold. First, we sought to replicate L's vantage-point-dependent cueing effects using hour of the day rather than months of the year. Second, we sought to assess whether non-synaesthetes would show cueing effects from visually and aurally presented hour units. Here, our rationale was that since the clock face is arguably the one standard manner in which time units are allocated to spatial locations for those without synaesthesia, then the non-synaesthetes might also show hour-name cueing effects. That is, the nighttime hours of 2 A.M., 3 A.M., 4 A.M., might cue attention to the right and the daylight hours of 8 A.M., 9 A.M., 10 A.M., might cue attention to the left. L's multiple vantage points for viewing her mental clock, as well as the fact that a clock face is presumably the manner in which non-synaesthetes would likely map time units to space, afford a number of interesting predictions related to L and to time-space synaesthesia in general. If hour names can trigger shifts of L's visual attention, then L should be quicker at detecting targets that fall in the synaesthetically cued location versus the opposite (invalid) side of space. One salient attribute that appears to differentiate synaesthetes' experience of spatial forms from non-synaesthetes' spatial forms (e.g., the standard number line, the clock face) is that synaesthetes spatial forms are more vivid and intense than their non-synaesthetic counterparts. If so, this should influence the *magnitude* of cueing effects. In other words, if the spatial forms of time-space synaesthetes were more vivid than non-synaesthetic spatial forms (such as the standard clock face), then we would expect larger cueing effects for the synaesthete compared to the non-synaesthetes.

Crucially, if it is also true that L's vantage point changes when she hears the hours named instead of sees them, those same daylight hours that cued her to her left side of space when visually presented should now orient her attention to her right side of space, when these hours are aurally presented. In sum, if the visual and aural inducers lead to different vantage points we should find a three-way interaction between the type of inducer (visual and aural), the hour cues (daylight hours *vs* nighttime hours) and side of target (left and right) – the same triple interaction that we showed in Experiment 1. Finally, we expect that even if non-synaesthetes do show cueing effects, because of a canonical representation of the standard clock face, these effects will be the same for auditory and visual presentations of the time units (i.e., they will NOT show vantage point shifts) and will fail to show a significant three-way interaction.

## 3.1. Methods

### 3.1.1. Participants

The same participants that took part in Experiment 1 participated in Experiment 2.

### 3.1.2. Stimuli and design

The design was the same as Experiment 1, except the six time cues were the hours of the day (2 A.M., 3 A.M., 4 A.M., 8 A.M., 9 A.M., 10 A.M.). In one condition the hours were presented visually in the center of the display, and in another condition they were broadcast aurally over a built in computer speaker.

### 3.1.3. Procedure

The procedure was identical to that of Experiment 1. Participants were to respond as quickly as possible once targets were detected, and to withhold responses on catch trials when no targets were presented.

## 3.2. Results and discussion

L made few errors on 'catch' trials (98% correct). Again, only participants that scored above 80% on catch trials were included in the analysis, which resulted in two being excluded. Observations that were ±2.5 SDs from that individuals cell mean were considered outliers. This resulted in 5.2% trials being discarded from the synaesthete and an average of 6.01% from the controls. We used the same 3-factor ANOVA as that used as Experiment 1, with the Bonferroni correction (alpha level of .005) to control type-I error rates for multiple tests. As predicted, L showed a significant 3-way interaction between type of inducer, hour cues, and side of target [$F(1, 904) = 28.75$, $p < .0001$]. The separate analyses for each of the controls failed to show this interaction (F-statistics of the controls ranged from .01 to 3.14 – values whose probability failed to be below our Bonferroni corrected alpha level of $p < .005$).

Planned comparisons revealed the source of the 3-way interaction for L, and can be seen by the solid and dotted lines connecting the key pairs of means in Fig. 4 (the error bars represent the 95% confidence intervals). We predicted that when visually presented with the daytime hours, L's attention would be cued to the left. Supporting our prediction, after daylight hour presentations (8 A.M., 9 A.M., 10 A.M.) left targets ($M = 235$ msec) were detected faster than right targets ($M = 415$ msec). This contrast is shown with the positively sloped solid line in Fig. 4A. As well, we predicted that the nighttime hours (2 A.M., 3 A.M., 4 A.M.) should cue her attention to the right. Following nighttime hour presentations, right targets ($M = 240$ msec) were detected faster than left targets ($M = 421$ msec) – see the negatively sloped dotted line in Fig. 4A. For the aural cues (shown in Fig. 4B), we predicted the opposite pattern of cueing. Namely, daytime hours should now cue attention to the right. Supporting our prediction, after daytime hour presentations right targets ($M = 238$ msec) were detected faster than left targets ($M = 393$ msec) – see the sloped solid line in Fig. 4B. Likewise, we predicted that nighttime hours should now cue attention to the left. Following nighttime hours presentations, left targets were detected faster ($M = 237$ msec) than right ($M = 365$ msec), – see the positively sloped dotted line in Fig. 4B. For these planned comparisons all $t$ values $>20.0$, and all $p$ values $<.0001$. These findings parallel those found for the months in Experiment 1, and further show that L's synaesthetic representations of the hours of the day can bias her spatial attention to those locations. L also showed a change in vantage point according to whether she saw or heard the hours presented, replicating the vantage point change found with the months (Experiment 1).

Fig. 5 illustrates the mean RTs of the control participants, with bars around the means reflecting the 95% confidence intervals. The asterisks denote L's mean RTs. As shown in Fig. 5, L's means lie within the range of control means for synaesthetically cued (valid) trials, but outside of the range of controls for invalid trials. As expected, controls failed to show the triple interaction shown by L. Contrary to our expectations, controls as a group also failed to show the two-way interaction where daylight hour cues would facilitate right target detection, and nighttime hour cues would facilitate left target detection [$F(1, 56) = .177$, *n.s.*]. Even on an individual

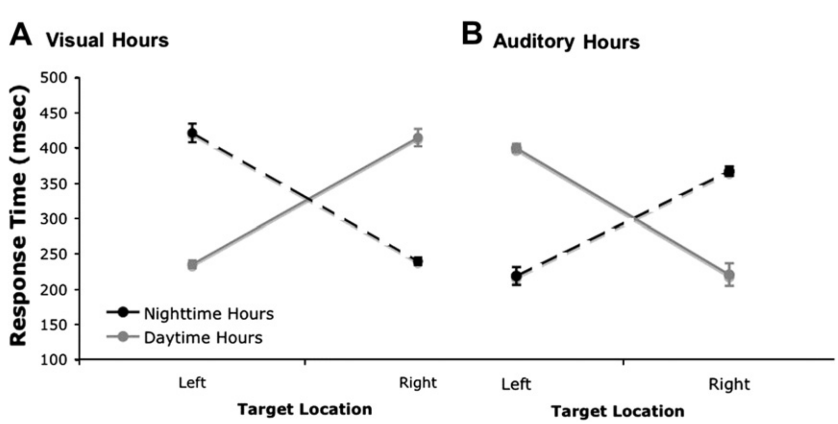


**Fig. 4 – Mean RTs of the synaesthete (L) for Experiment 2 (Hours) across the two conditions: visual (Panel A) and auditory (Panel B). Note that the error bars represent the 95% confidence intervals around the mean.**

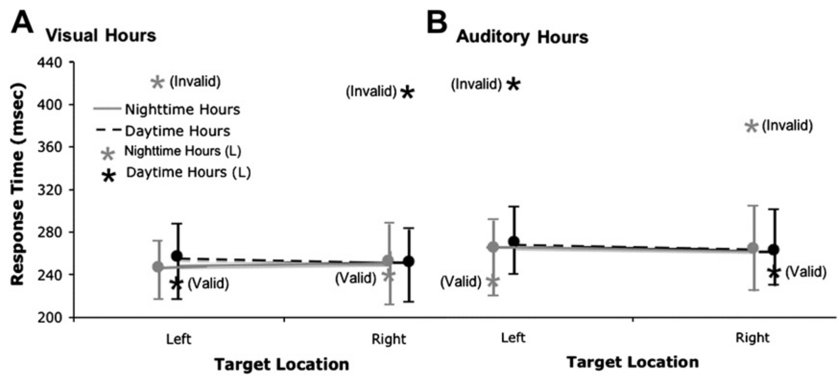


**Fig. 5 – Mean RTs of the Controls for Experiment 2 (Hours) across the two inducer conditions: visual (Panel A) and auditory (Panel B). The error bars represent the 95% confidence intervals of participant means. The asterisks represent L's data, showing that her means fall inside the range of Controls during the valid trials (*valid* ), while she is an outlier during invalid trials (*invalid* ).**

level, none of the controls showed this predicted interaction (largest $F$-value among the controls being $F(1, 896) = 5.49$, *n.s.*). Yet, a recent study by Dodd et al. (2008) demonstrated that the Fischer cueing task only works for numbers, and not for other ordinal sequences like months or letters in non-synaesthetes. Thus, our results are in line with their findings.

The cueing effect sizes for L and each of the controls are presented in Table 2. The left side of Table 2 shows the RTs for the valid and invalid trials and the magnitude of the cueing effect for visual hour cues. Once again "valid" trials are valid from the synaesthete's perspective; for visual presentations nighttime hours followed by targets on the right and afternoon hours followed by targets on the left comprise valid trials (the same mappings occur for controls using the standard clock face). For the auditory cues, "valid" trials for the synaesthete are opposite to controls (so to calculate controls' cueing effect sizes keep the magnitude and merely reverse the sign). As can be seen in Table 2, the cueing effect sizes are much larger for the synaesthete L, than for any of the controls for both the visual and auditory presentations. To directly compare L's cueing effect sizes to those of the control sample we again used Crawford and Garthwaite's (2005) RSDT. For the visual cues L showed significantly larger differences between valid and invalid RTs (cueing effects) than controls RSDT $t(7) = 17.93$, $p < .0001$. She also showed larger cueing effects than controls with auditory cues RSDT $t(7) = 24.89$, $p < .0001$.

## 4. General discussion

The results of these experiments replicate those found by Smilek et al. (2007). Like Smilek et al., we showed that time units (months and hours) can direct the attention of a time-space synaesthete independent of her intention. Even though L was aware that the time cues were not predictive of the target location, she could not process the time unit without it biasing her attention to the corresponding location in space. In both experiments, when the target fell in the location cued by the time cue, she was significantly faster than when the target fell in the opposite location. We also extended the work

**Table 2 – Experiment 2: RT and SDs in msec for the Svnasethete L and each of the eight non-syneasthetic controls (C) for visual and auditory hour cues. The cueing effects are denoted in bold and represent the difference in RT between the valid and invalid trials (invalid – valid). Note that the validity refers to whether the target was aligned (valid) or misaligned (invalid) with L's synaesthetic representation.**

| Inducer | Visual | | | | | Auditory | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Valid | | Invalid | | Cueing effect | Valid | | Invalid | | Cueing effect |
| | RT | (SD) | RT | (SD) | RT (In V-V) | RT | (SD) | RT | (SD) | RT (In V-V) |
| L | 237 | (30.1) | 417 | (70.9) | **180** | 237 | (29.6) | 379 | (69.2) | **142** |
| C1 | 271 | (37.0) | 266 | (34.0) | **−5** | 278 | (50.0) | 279 | (50.6) | **1** |
| C2 | 257 | (42.1) | 257 | (47.7) | **0** | 263 | (25.0) | 264 | (31.0) | **1** |
| C3 | 285 | (59.1) | 272 | (48.6) | **−13** | 284 | (45.8) | 285 | (59.1) | **1** |
| C4 | 268 | (49.5) | 257 | (40.3) | **−11** | 246 | (38.2) | 248 | (39.5) | **2** |
| C5 | 231 | (28.0) | 231 | (26.9) | **0** | 269 | (28.9) | 268 | (30.1) | **−1** |
| C6 | 214 | (22.0) | 214 | (27.5) | **0** | 223 | (23.9) | 225 | (22.8) | **1** |
| C7 | 235 | (20.8) | 235 | (20.6) | **0** | 227 | (19.2) | 228 | (21.7) | **1** |
| C8 | 273 | (31.7) | 270 | (28.3) | **−3** | 267 | (27.2) | 266 | (27.3) | **−1** |

of Smilek et al. by showing that time-space associations can be dependent on the modality of the inducer (visual or auditory). This was the case for L who demonstrated opposite cueing patterns between the auditory and visual conditions (Figs. 2 and 4). For instance, when visually presented with the months *January*, *February*, or *March*, she was significantly faster to detect targets located to her left side of space (consistent with her synaesthetic locations of these months), whereas when these exact same months were presented aurally the reverse pattern emerged; she was faster to respond to targets on her right side (consistent with the synaesthetic location of the months from her auditory vantage point). This was also true for the hours of the day in Experiment 2. Therefore, our results provide objective evidence consistent with L's subjective reports of her modality-dependent mental vantage point changes. They also conclusively show that these synaesthetic representations are real spatial experiences that do indeed direct her spatial attention and can influence her behaviour.

Although our research (as well as Smilek et al., 2007 and Price and Mentzoni, 2008) clearly demonstrates the robustness of these time-space pairings for individuals with time-space synaesthesia, there is much evidence that ordinal sequences (like months, days of the week, letters, and numbers) are spatially coded in non-synaesthetes as well (Dehaene et al., 1993; Fischer et al., 2003; Gevers et al., 2003, 2004). For example, Gevers et al. (2003) used a SNARC-type (non-cueing) task and had participants make temporal order judgments concerning the months January to April and September to December by identifying whether a month came before or after the month of July (order-relevant task). They found that earlier months were responded to faster with the left hand and later months faster with the right hand, leading the authors to conclude that the ordinal representation of time was spatially defined. Yet, in a second experiment, Gevers et al. introduced an order-irrelevant task (i.e., does the month end in the letter R or not?) and also found a SNARC effect, albeit of a significantly smaller effect size than the effect size for the order-relevant task. The finding that the even a small SNARC effect was present in a task that only required superficial analysis of the month name without having to refer to any sort of spatial reference, suggested that the spatial component of the time unit could be activated into a sequence automatically. It should be noted however, that Gevers et al.'s results were not replicated in a recent study by Price and Mentzoni (2008), demonstrating how variable these effects are across participants and tasks.

In the Gevers et al. (2003) task the goal was to make before/after judgments about the presented month names (non-cueing task), whereas in the present study the goal of the task was to detect simple targets (cueing task). Participants were expressly told that that the month names were essentially superfluous (i.e., that they did not predict target locations). The failure to show any cueing effects for month names among the control participants in the present study indicates that for non-synaesthetes any associations between months and spatial locations are far from robust, and do not lead to cueing effects in a simple target detection task. It has been suggested by Galfano et al. (2006) that the passive viewing of a cue might not be sufficient to bias attention to a particular location in space that otherwise would occur if the cue was actively processed. For instance, just presenting an irrelevant number or month name on a computer screen is likely not strong enough to activate a mental calendar or number line and allow retrieval of the month's position in a sequence. For non-synaesthetes, this might account for the variability across studies that attempt to provide objective evidence that the spatial mappings of numbers and time units influence overt behaviour. In general for non-synaesthetes, the magnitude of effect sizes might be influenced by the type of judgment made (it seems that ordinal information might lead to smaller effects than magnitude information, but see Tang et al., 2008), and cueing effects appear to be less robust and reliable than when stimuli are actively processed (as in the SNARC-type tasks). Thus, perhaps the lack of cueing effects in the non-synaesthetes is not surprising in the month cueing task.

We were somewhat surprised that in Experiment 2, for the non-synaesthetes hour names (e.g., 3 A.M.) failed to activate the hour-space mappings of the standard clock face to a point where they influenced behaviour. No cueing effects were observed either at the group or the single subject level. Ristic et al. (2006) did show cueing effects of numbers when participants were told to *imagine* that the numbers represented the hours on a clock. Likewise, Bächtold et al. (1998) showed SNARC effects using a non-cueing task that corresponded to different mental reference frames that were induced by asking participants to imagine numbers on a ruler versus a clock face (also see Price, 2009, this issue). In the current study, no such instructions were given to participants. This supports the argument that at least for non-synaesthetes cueing effects will arise only through active processing of the cue (e.g., imagining the hour positioned on a clock face). The cueing effects found by Ristic et al. might have also been enhanced by telling participants to imagine a clock face, and including four possible target locations (left, right, top, and bottom) that correspond more to the clock face than the two target locations (right and left), used in Experiment 2. Essentially, the importance of the Ristic et al. study to the current work was that it highlights that the mappings between time-units and space are far from robust in non-synaesthetes, and whether or not these mappings can be empirically demonstrated in cognitive tasks depends on the specifics of the experimental design.

In contrast to the null effects with the non-synaesthetes, for the synaesthete L the mappings between time and space were both strong and reliable even using a cueing task. Thus, L's synaesthetic spatial maps likely represent a conscious and highly enriched version of the spatial maps found in non-synaesthetes and can be elicited by passive processing of the time cue. The findings of Experiment 2 in which L's spatial form approximated the standard clock face, are particularly important since they provide objective support for the contention that the spatial forms of synaesthetes are more vivid and intense than those of non-synaesthetes.

Arguably what is most fascinating and unique regarding L's time-space pairings was the complete reversal in RT patterns for heard months (and hours) compared to seen months (and hours). These opposing patterns support her subjective reports of viewing her spatial forms from opposite mental vantage points – essentially reversing her outlook on time! It is interesting to speculate why L might have developed these different mental vantage points within her spatial representation of time units. L reports that she prefers to view her time units from an auditory vantage point and does so even when thinking about the time units. One may speculate that when L was a child, she first learned the names of the months by hearing them. To aid in her month learning, she mapped the month names to arbitrary sequential locations in space (with January, on her right, April in front of her, July on her left and subsequent months extending away from her). These right-to-left mappings, and the L shaped space that formed early on in her pre-school years were essentially unconstrained by cultural influences. When she attended school however, the month names in addition to being presented aurally would also be presented visually by the teacher. Here cultural influences would dictate that January would be in the leftmost position followed by February, March, April, extending in a rightward direction (for a recent review of how culture can dictate and influence the development of imagined space for numbers and time units see Hubbard et al., 2009). These visual depictions of (culturally defined) left-to-right months shown by her teachers, would conflict with L's right-to-left sequencing of the months. One way of resolving the conflict of these visually presented months which were portrayed from left to right, with her idiosyncratic representation of months which (at least for the early months) go from right to left, was to maintain her L shaped space, but mentally view it from a different (opposite) location (from the crux of the 7). By viewing the space from this new location, January, February, March, would run from left to right (as she was shown in school), but now the tail of her space would run behind her rather than away from her (see Fig. 1). A similar logic might explain her clock face mappings. Although this speculation is admittedly post-hoc, Stewart et al. (in prepration) are currently investigating this possibility.

The present findings are in some ways reminiscent of the classic study by Bisiach and Luzzatti (1978) who asked two left neglect patients to imagine and describe landmarks of the Piazza del Duomo in Milan (a familiar location to both patients). Patients mentally viewed the square first looking from the steps of the Cathedral onto the square. From this vantage point they described only those landmarks that appeared on the right side of the square and ignored all those on the left side. However, when they changed their mental vantage point to the opposite side of the square (now facing the Cathedral), the patients described the buildings and landmarks that they had just ignored. This study showed that neglect following stroke influenced the experience not only of the external world, but also the internal representations of that world. It also showed that just as we can change our vantage point by changing locations in the physical world, we can mentally change our vantage point within an internal representation of that world. In the current study, we conceptually replicated these general principles. We showed that mental vantage point had a profound effect on attention using a cueing paradigm. We presented month or hour names that were associated with a particular vantage point, and biased attention to a particular side of space. We then showed that changing mental vantage point (by presenting the same month or hour names in a modality associated with a different vantage point) biased attention to the previously unbiased side of space. Thus, while the neglect patients used changes in mental vantage point to name previously neglected locations, L used changes in mental vantage point to bias her attention to formerly unbiased locations in space.

Moreover, the current work also informs us about the correspondence between real-world space and imagined space. In the real world, we often view spaces from different vantage points. In the neglect study, presumably, the patients had physically experienced the Piazza Del Duomo from different vantage points (facing the church *vs* sitting on the church steps). In the current study, profound effects of vantage point emerged in a space that the synaesthete *had never actually experienced* in the physical world. Her calendar space is entirely mentally generated. As such, one might imagine that there would only be a single canonical perspective for viewing this space. However, the current results conclusively show that for this mentally generated space (that has no real-world equivalent), different mental vantage points are both possible, and are systematically employed by the synaesthete. The current findings suggest, therefore, that the characteristics that govern external spaces (the fact that we can explore a space from multiple vantage points) appear to also govern internal spaces. This interpretation maps on to the subjective descriptions of a number of synaesthetes who report being able to navigate through their mental calendars, which like L's, they have never physically experienced. In addition, this study shows that the vantage point from which this internal space is viewed can have dramatic influences on detecting targets *in external space*. That is, while January is on her left in this mentally created *internal* space, it influences her ability to detect targets on the left side of a computer screen, presented in real-world *external* space.

The precise mechanisms underlying these profound differences observed between L and the eight controls in our cueing tasks is currently being examined. However, there is growing evidence indicating that the parietal lobe is the main area responsible not only for providing connections between numbers and space, but also ordinal sequences and space, as well as aspects of spatial attention (Tang et al., 2008; also see Hubbard et al., 2005, 2009 for reviews). Tang et al. (2008) used functional magnetic resonance imaging (fMRI) to study which brain areas were dedicated to cardinal versus ordinal properties of number forms. Their findings showed distinct but partially overlapping neural networks in the intraparietal sulcus (IPS), which suggests that the IPS is not only involved in numerical sequences, but in processing non-numerical ordinal concepts as well. In terms of spatial attention, the posterior IPS has been shown to be involved in activating different spatial reference frames, where the human homologue of the monkey lateral IPS codes for eye-centered reference frames (Ben Hamed et al., 2001) and ventral IPS deals with head-centered reference frames (Duhamel et al., 1997). Recent work on the SNARC effect has suggested that these spatial numerical associations are dependent on eye- and world centered reference frames (Hubbard et al., 2005, 2009; Wood et al., 1993). Therefore, it appears that certain areas in the posterior IPS are responsible for the cross-activation of ordinal sequences and space in synaesthetes as well as in non-synaesthetes. From our behavioural data here, we can only speculate that these connections might be stronger in synaesthetes than non-synaesthetes – a situation that would account for the more robust cueing effects in L compared to the non-synaesthetes. It is interesting to consider how a lifetime of experience consistently making associations between time units and space could modify (by possibly facilitating) the connectivity between spatial (human ventral intraparietal – VIP and lateral intraparietal – LIP) and ordinal (posterior IPS) areas within the parietal cortex.

In sum, this study makes six claims. First, visually presented month names can bias the spatial attention of time-space synaesthetes. Second, aurally presented month names can also bias the spatial attention of individuals with spatial forms for time units. Third, aural and visual presentations of the time units can elicit different mental vantage points from which L can view her spatial forms. Fourth, the ability of time units to bias attention appears to be stronger for synaesthetes than non-synaesthetes, even when the time units under consideration conform to the standard clock face. Fifth, mental spaces such as L's 7 (or L) – shaped mental calendar, which has no real-world correspondence, nevertheless adheres to the characteristics of real-world spaces. Specifically, just as we can experience real-world external spaces from different vantage points, she can experience this purely internal space from different vantage points. Lastly, the cueing effects reveal that vantage point changes within an internal space can influence the ability to attend to and detect objects in external space. Such a finding highlights that although real-world experience may help us to mentally view a given space from different vantage points, real-world experience of the space is not necessary – strong vantage point effects can be demonstrated even in a mental space without any real-world correspondence. Most importantly, these vantage point effects pertaining to internal space can influence the detection of objects out there in the real world.

In closing, a unifying feature of the self-reports of time-space synaesthetes is that they find their spatial calendars cognitively useful. Indeed, Simner et al. (2009, this issue) showed that synaesthetes outperform non-synaesthetes on a variety of temporal and spatial tasks. However, spatially localizing to-be-remembered items is also a well-known mnemonic technique (method of loci) that non-synaesthetes can learn to employ. This study shows that spatial forms (that might aid in memory retrieval) can be accompanied by highly distinct vantage points, which auditory and visual stimuli can differentially activate. By understanding the relationship between spatial forms and these mental vantage points, we can hope to gain a better understanding ultimately of how spatial forms may prove useful for synaesthetes and non-synaesthetes alike.

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