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SPECIAL SECTION: EDITORIAL

Synaesthetic visuo-spatial forms: Viewing sequences in space

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Introduction

A small sub-set of the population experience an unusual phenomenon in which sequences (such as Arabic numerals, letters of the alphabet, days, months etc.) are visualized as occupying particular spatial arrays, and these individuals are known as *visuo-spatial synaesthetes*. Their *visuo-spatial forms* depict sequenced units (e.g., *January*, *February*, *March*…) laid out in set spatial arrangements which are open for conscious inspection, and which can be highly convoluted and idiosyncratic. Many examples of these spatial arrays are given in the following special section on *Synaesthetic Visuo-spatial Forms* (e.g., Figures 1-6, Simner et al., 2009, this issue; Figure 1, Jarick et al., 2009a, this issue) which explores the roots of this unusual phenomenon and its relationship to normal processing. Visuo-spatial synaesthetes may possess one or many visuo-spatial form(s), and these exist either in the peripersonal area outside the body, or in mental space within the mind's eye. Although these spatial arrangements differ from synaesthete to synaesthete, they tend to be highly consistent within each individual over time, and many visuo-spatial synaesthetes are simply unaware that their life-long experience of sequences in space differs in any way from the experiences of the average person.

Synaesthetic spatial forms can be induced by a range of different ordinal sequences, although forms triggered by time-units (e.g., days or the week, months of the year) and by numbers and letters are particularly common (see Sagiv et al., 2006 for data on the prevalence of different visuo-spatial forms). Other rarer cases have involved forms for sequences such as shoe sizes, temperatures, historical eras, the Indian caste system, and even prime-time television schedules (Cytowic and Eagleman, 2009; Hubbard et al., 2005; Sagiv et al., 2006; Seron et al., 1992; Seymour, 1980) and one particularly extra-ordinary case is reported in this special section by

Hubbard et al. (2009, this issue). Their synaesthete, DG, has an astonishing set of at least 58 different forms, and these include spatial arrays not only for Arabic numerals, alphabet, and time-units, but also for other numerical sequences (e.g., Roman numerals), different units of measure (e.g. kilograms, kilometres and degrees), financial series (stock prices, tax rates, etc.) and even the sequenced order of pure-bred dog naming conventions. In their empirical work, Hubbard and colleagues have focussed on DG's form for Arabic numerals, and indeed, three papers in total in this special section investigate synaesthetic number lines (also Ward et al., 2009, this issue; Jarick et al., 2009a, this issue). The remaining papers examine synaesthetic forms encoding time units; specifically, forms for hours within a day (Jarick et al., 2009b, this issue), for days within a week (Price, 2009, this issue), for months within a year (Eagleman, Price, Jarick et al., 2009b, this issue) and for years within a century (Simner et al., 2009, this issue). As such, they cover a range of manifestations across a range of synaesthetic individuals, and their data converge to provide the most in-depth examination to date of this unusual phenomenon.

Visuo-spatial forms, synaesthesia, and SNARC

Historically speaking, visuo-spatial forms were first reported by Galton (1880a) but received fairly small exposure in the psychology literature over the following century. In recent years, the phenomenon has established a gradually increasing presence in psychological and neuroscientific reports (Cytowic, 2002; Hubbard et al., 2005; Price and Mentzoni, 2008; Sagiv et al., 2006; Seron et al., 1992; Seymour, 1980; Smilek et al., 2007) and this steady ascent has been carried by increasing interest in two related fields. The first is the notable growth in the general field of synaesthesia research, which has witnessed a considerable renaissance in the past 10 years, and has itself been the focus of a recent special issue of *Cortex* (*Cognitive Neuroscience Perspectives on Synaesthesia*, volume 42, issue 2, 2006). Synaesthesia is a multi-variant neurological condition with a genetic basis (Asher et al., 2009), in which perceptual or cognitive activities (e.g., listening to music, reading) trigger exceptional experiences (e.g., of colour, taste). Synaesthetes might see colours when they hear sounds, for example (*music-colour synaesthesia*; Ward et al., 2006) or experience tastes in the mouth when they read or hear words (*lexical-gustatory synaesthesia*; Simner and Ward, 2006; Ward and Simner, 2003) and so on. The condition is characterised by the pairing of a particular triggering stimulus (or *inducer*) with a particular resultant experience (or *concurrent*; Grossenbacher, 1997) and visuo-spatial forms are considered by many to be a variant of synaesthesia which pairs sequenced units (inducer) to spatial codes (concurrent).

A second influence on research into synaesthetic visuo-spatial form has been the considerable interest in the phenomenon known as *SNARC* (*spatial-numerical association of response codes*). The SNARC effect is an illustration of the spontaneous association in all people between numbers and space, and of how this affects behaviour. In a range of tasks where participants are asked to respond to on-screen stimuli with button presses, they typically show faster left-than-right hand responses to smaller numbers, and the reverse for larger numbers (Dehaene et al., 1993; for recent reviews, see Fias and Fischer, 2005; Hubbard et al., 2005; Wood and Fischer, 2008). SNARC effects are known to mimic writing conventions, since readers of languages that unfold left-to-right (e.g., French) show left-hand biases for low numbers, while readers of right-to-left writing systems (e.g., Iranian) show right-hand biases for low numbers (Dehaene et al., 1993). This SNARC response bias arises even in tasks that do not overtly probe spatial properties, such as a number parity task (judging whether a number is odd or even), or a magnitude task (judging whether a target number is smaller or larger than a reference number; Dehaene et al., 1993; Dehaene et al., 1990). The SNARC effects has been interpreted as evidence that numbers are mapped onto an implicit line which runs horizontally in space, and which links left-space to early numbers for those who use writing systems that unfold from the left (Dehaene et al., 1993). The SNARC finding has proved a fruitful line of research and the relationship between space and number has formed the theme of another recent *Cortex* special issue (*Numbers, space, and action,* volume 44, issue 4, 2008).

Evidence for mappings between numbers and space in the general population has not been limited to the SNARC effect alone. This mapping has also been suggested by *cued detection* tasks, in which participants must detect targets at various positions on screen, after first viewing a number, or some other cue. Fischer et al. (2003) show that low numbers serve as better cues for left-sided targets, and high numbers for right-sided targets. SNARC-type effects have also been shown in tasks such as backward priming, where responses are faster for smaller numbers followed by left- (vs. right-) sided cues, and the reverse for larger numbers (Stoianov et al., 2008). Indeed, a range of methodologies have now revealed similar spatial compatibility effects that suggests a mapping between numbers and space (e.g., Casarotti et al., 2007; Zorzi et al., 2002; Zorzi et al., 2006), and a fuller review of this literature is given by Hubbard et al. (2009, this issue).

Spatial compatibility effects such as the SNARC have also now been demonstrated for a range of different stimuli (see Cohen Kadosh et al., 2008b for review), and these include days if the week (Gevers et al., 2004), months of the year (Gevers et al., 2003, see also Price, 2009, this issue), acoustic pitch (Cohen Kadosh et al., 2008a; Rusconi et al., 2006), and other time intervals (Ishihara et al., 2008). The common feature of these stimuli is their sequential nature, suggesting that ordinality rather than numerical magnitude *per se* may be the key determinant in spatial mapping. Of particular interest here is that these spatial compatibility effects raise the possibility that those with explicit synaesthetic visuo-spatial forms may provide an ‘open window’ on the implicit sequence-space associations that exist in all people. One aim of this special section is to explore this link: the papers contained here examine the roots of synaesthetic visuo-spatial forms, their phenomenology, their links to normal processing in all people, and the ways in which they might impact on the general cognitive abilities of the individual.

How informative are SNARC-type effects in visuo-spatial synaesthetes?

SNARC findings and other similar effects are particularly interesting when found in visuo-spatial synaesthetes, not only for what they can tell us about synaesthesia, but for what they might also indicate about the nature of SNARC-type effects in all people.

Informative for visuo-spatial synaesthesia

The usefulness of SNARC (and other spatial compatibility) methodologies in the study of synaesthetes has already been demonstrated, and has shown both similarities and differences between synaesthetic visuo-spatial forms and the implicit forms in the broad population. Visuo-spatial synaesthetes, like all people, show handedness biases in SNARC-type tasks, but their performance is modulated by the distinctive lay-out of their forms. Price and Mentzoni (2008) asked visuo-spatial synaesthetes to press a button to indicate whether certain months fall in the first or second half of the year (a type of magnitude judgment), and their performance was compared to non-synaesthete controls. In a similar task, Gevers et al. (2003) had shown that non-synaesthetes have a typical SNARC-type effect: early months (e.g., *January*) are responded to faster with the left (vs. right) hand, and the reverse for later months (see also Price, this issue). When visuo-spatial synaesthetes were tested (Price and Mentzoni, 2008), they too showed handedness effects, but their responses mimicked the idiosyncrasies of their reported visuo-spatial form. For example, synaesthetes with forms in which *January* fell in the left-side of space showed a typical month-SNARC effect (i.e., they responded faster to *January* with their left hand) while synaesthetes whose visuo-spatial form took the opposite direction (i.e., *January* falling in the right side of space) showed a reversed month-SNARC effect, and responses to early months were now faster with the right hand. In this way, SNARC-type paradigms can be seen to lend support for the reported phenomenologies of visuo-spatial forms.

Three papers in this special section add to these findings with different populations of synaesthetes, different tasks, and different types of visuo-spatial forms. Jarick et al. (2009a, this issue) show that the particular layout of their synaesthete L's number form influences her performance in a number parity task. Jarick and colleagues altered the orientation of response buttons such that they were aligned with L's form, or were not aligned (e.g., where L's form moved vertically, buttons were arranged either vertically or horizontally). L's reaction times were affected only when the spatial layout of response buttons was compatible with the orientation of her mental number line. For example, when responding to a portion of the visuo-spatial number line in which numbers are laid out vertically, L showed a vertical SNARC effects (i.e., faster bottom-than-top responses for numbers on the bottom of her number line). However, when the buttons were arranged horizontally, they no longer matched the orientation of L's number line, and no SNARC effects were found.

A similar effect is also shown here in cued detection tasks (Fischer et al., 2003). Jarick et al. (2009a, this issue; Experiments 2 and 3) tested two synaesthetes whose forms run bottom-to-top (i.e., vertically) for numbers 1 through 9, but which run left-to-right (i.e., horizontally) for numbers 10 through 20. Jarick et al. found that synaesthetes were cued by numbers to locations in space predicted by their number forms. When cued with a number between 1 and 9 (where the form runs vertically), synaesthetes showed a vertical (but not horizontal) cueing effect (i.e. faster bottom-than-top responses for numbers at the bottom of her number line, e.g., *1*, *2*). However, when cued with numbers between 10 and 20 (where the number form runs horizontally) synaesthetes now showed a horizontal (but not vertical) cueing effect (i.e., faster left-than-right responses for numbers on the left of her number line, e.g., *10*, *11*). These findings lead Jarick et al. (2009a, this issue) to conclude that numbers can direct spatial attention to idiosyncratic locations for these number-form synaesthetes. Moreover, cuing effects were found at very short delays (50 ms after the offset of the cue) suggesting that visuo-spatial forms arise early and automatically.

Cueing effects are also shown using month stimuli (Jarick et al., 2009b, this issue; see also Smilek et al., 2007). Jarick and colleagues (2009b, this issue) present the unusual case of a synaesthete whose visuo-spatial month-form changes according to the input modality of the month-name. For example, when *seeing* the word *January*, the synaesthete's visuo-spatial form maps January to the left, but when *hearing* the word January, the visuo-spatial form now maps *January* to the right. This switching was verified using a cued detection paradigm with both visual and auditory cues: when *seeing* month-names, responses were faster for left-sided targets following early months, but when *hearing* month names, responses were faster for *right*-sided targets following early months (and the reverse pattern for later months). These changes in the relative positioning of months on the synaesthete's month-form arise from a change in her vantage point (in the same way that the bow of a ship would switch from left- to right-space if viewing the boat first from port-side and then from starboard-side). Hence, this cued detection task is one particularly elegant way of providing evidence of switches in vantage point, and Jarick et al. (2009b) use a similar task to also verify a switch in vantage points over a form for hours of the day.

Hubbard et al. (2009, this issue) also use a cued detection task to provide evidence of idiosyncratic visuo-spatial number form, in much the same way as Jarick et al. (2009a, this issue; see above). Moreover, Hubbard and colleagues also provide similar support using a *number-pair comparison task* (where participants are required to indicate which of a pair of numbers is larger). Their synaesthete, DG, has a synaesthetic number line running vertically, from bottom to top. DG responded faster in bottom-sided responses when the mean of the number pair was small (less than or equal to 5) compared to when it was larger (greater than 5), and vice versa for top-sided responses. The effects occurred only when targets were laid out vertically (i.e., with the same orientation as his vertical number line) but not when they were laid out horizontally (conflicting with the orientation of the number form). These data reflect similar findings in number-pair comparison for synaesthetes in Sagiv et al. (2006) and Piazza et al. (2006). Nonetheless, Hubbard et al. found no similar SNARC-type effects in either a parity task (see also Piazza et al., 2006) or a magnitude task (when numbers were compared to an internal reference). Hubbard et al. suggest that, for this synaesthete at least, spatial forms are most strongly invoked when the task and/or stimuli have some spatial dimension (as in spatial cued detection, or number-pairs presented in particular spatial orientations). Nonetheless, another paper here, Jarick et al. (2009a, this issue), did find an influence of the synaesthetic form in a number parity task (see above), suggesting that for some synaesthetes at least, visuo-spatial form are evoked strongly enough to influence behaviour in tasks that have no spatial component at all.

In summary, five different types of spatial compatibility effect have verified here the phenomenon of synaesthetic visuo-spatial forms: number cued detection (Jarick et al., 2009a, this issue; Hubbard et al., 2009, this issue), month cued detection, hours cued detection (Jarick et al., 2009b, this issue), numerical parity (Jarick et al., 2009a, this issue, but see Hubbard et al., 2009, this issue) and in a number-pair comparison task (Hubbard et al., 2009, this issue). They were not found in a numerical magnitude task with an internal reference (Hubbard et al., 2009, this issue). In all cases where effects were found, the behaviour of synaesthetes was shown to be different to matched controls, either because controls showed no effect where synaesthetes did (e.g., no cued detection effect in controls for hours; Jarick et al., 2009b, this issue), or because synaesthetes showed no effects where *controls* did (e.g., controls show a horizontal parity-SNARC effect, but not a synaesthetes whose number form runs vertically; Jarick et al., 2009a, this issue), or because synaesthetes showed significantly *stronger* effects than controls (e.g., both synaesthete and controls showed a mapping between larger numbers and high vertical space in a number magnitude task, but the effect was significantly stronger for the synaesthete; Hubbard et al., 2009, this issue). We now examine the nature of these control effects more closely.

Informative for number (and other sequence) cognition

Clearly, SNARC tasks and related approaches can prove useful in validating the reports of visuo-spatial synaesthetes, but the reverse is also true: studies of visuo-spatial synaesthetes might provide a useful tool for inspecting the validity of SNARC-type effect in all people. First, and most pragmatically, SNARC studies on synaesthetes also test control populations, and so add to data on normal processing simply by their ability – or failure – to replicate previous findings in the general population. Replicability is an important consideration in any area of research, but is particularly important in studies of sequence/number cognition because SNARC-type spatial compatibility effects in the general population have varied in their apparent robustness across different types of task (e.g., parity judgment, magnitude judgment, cued detection etc.) and across different types of stimuli (numerals, months, hours etc.; e.g., Dodd et al., 2008, Gevers et al., 2006b; Ito and Hatta, 2004; Price, 2009, this issue, Zorzi et al., 2006). These variations are informative for establishing the conditions under which spatial mappings may arise.

Four papers in this special issue include assessments of non-synaesthete controls in SNARC and other spatial compatibility tasks, and provide useful data on the robustness of these effects in the general population. Price (2009, this issue) examines the month-SNARC effect in non-synaesthetes, and his study includes a re-analysis of data from Price and Mentzoni (2008). Price and Mentzoni's main finding was an illustration that the direction of SNARC effects for synaesthetes was predicted by the layout of their forms, but they failed to replicate Gevers et al.'s standard month-SNARC effect in non-synaesthetes (Gevers et al., 2003). This had raised questions about the robustness of this effect, and about the circumstances under which the month-SNARC might be manifested. However, in place of Price and Mentzoni's less sensitive ANOVA, Price (2009, this issue) performs a regression slope analysis on the same data and now reveals a standard SNARC effect in normal participants. This re-analysis converges with Gevers et al. (2003) by suggesting that SNARC-type effects can indeed be found in the general population for non-numeric month stimuli. Nonetheless, Price's reanalysis could only reveal a month-SNARC effect in a parity-type task (e.g., where January is considered 'odd', February 'even' etc.) but not in a type of magnitude task ('Do months belong to the first or second half of the year?'; similar to Gevers et al., 2003) which raises questions about the circumstances under which such SNARC effects might arise.

Other studies, too, question task-specificity in the month-SNARC finding: no effects were found in the general population when month-names were used in a cued detection task (Jarick et al., 2009b, this issue). Jarick and colleagues found that controls showed no difference in their abilities to detect cues on the left or right side of space following early versus later months of the year (or indeed, following early vs. later hours in the day), and this failure in month-cues supports another recent study by Dodd et al. (2008). Jarick et al. (2009b, this issue) suggest either that associations between months and spatial locations are not entirely robust in the general population, or that passive viewing of month-names might not be sufficient in the general population to bias attention to a particular location in space. Indeed, recent work by Ristic et al. (2006) and Galfano et al. (2006) show how context- and task-dependent cueing effects can be (see also Casarotti et al., 2007) and this may explain why they were not replicated here even for numerical stimuli (Jarick et al., 2009a, this issue; Hubbard et al., 2009, this issue), as other studies also now show (e.g., Bonato et al., 2009).

Finally, two studies here (Hubbard et al., 2009, this issue; Jarick et al., 2009a, this issue) replicate the standard parity-judgement SNARC effect for numbers in non-synaesthete control participants (Dehaene at al., 1993). Non-synaesthetes showed faster left-than-right responses to small single-digit numbers (e.g., *1*), and the reverse for large single-digit numbers (e.g., *9*). However, neither study was able to replicate previous findings of a small vertical parity-SNARC effect in controls (e.g., Gevers et al., 2006a; Ito and Hatta, 2004; Schwarz and Keus, 2004). Nonetheless, when the task was switched to a magnitude judgment (i.e., asking whether stimuli were larger or smaller than an external reference point), controls now showed not only the classical horizontal SNARC, but also a step-like SNARC in the vertical direction (Hubbard et al., 2009, this issue). There was also a near-significant effect in a number-pair comparison task (i.e., asking which of two numbers is larger; Hubbard et al., 2009, this issue): non-synaesthetes responded faster in vertical button presses for top responses when number-pairs were larger in numerical magnitude (Hubbard et al., 2009, this issue). Both findings are consistent with previous studies showing a vertical SNARC effect (Gevers et al., 2006a; Ito and Hatta, 2004; Schwarz and Keus, 2004) and are consistent, too, with studies that have suggested SNARC effects may be stronger and more step-like when access to numerical magnitude is specifically required to perform the task (Gevers et al., 2006b).

In summary, the studies here indicate that SNARC-type findings are not necessarily robust in the general population, and that they cannot be easily replicated under certain combinations of task and stimuli. It is important to point out that these studies *did* find significant results using those same tasks with synaesthete participants if predicted by their number lines (with the exception of the vertical parity task; Hubbard et al., this issue, Experiment 4) and this adds evidence of rigour in their designs. In addition, no studies here conflicted in their abilities to replicate any particular finding in controls, and more than one study concurred on the failure to replicate in some cases (e.g., in numerical cued detection; Hubbard et al., 2009, this issue; Jarick et al., 2009a, this issue).

Aside from the pragmatic consideration of testing non-synaesthete controls, studies on visuo-spatial synaesthetes also offer more *direct* information for research on normal number (and other sequence) processing. Although SNARC-type effects in the general population have traditionally been interpreted as evidence of a widely-held mental number line (and lines for other sequences), this interpretation has been questioned by recent work proposing alternative explanations. Proctor and Cho (2006) suggest that SNARC effects may simply reflect a shared semantic compatibility of markedness between "left" and "small" (see also Gevers et al., 2006b). In addition, Fitousi et al. (2009) have suggested that SNARC effects might reflect over-learned stimulus-response compatibility in a world where rulers, keyboards and other conventions have ubiquitously mapped lower numbers to left-hand space. Others have suggested a fundamental severance in the traditional notion of a unified mental number line, by suggesting that magnitude processing must necessarily precede spatial mapping (Santens and Gevers, 2008; see also Cohen Kadosh et al., 2008c). Despite these logical objections to the notion of a pervasive mental number line, the presence of a population of individuals who have *conscious access* to the very spatial mappings on which their SNARC effects are based, provides very strong evidence for a human predisposition to represent numbers and other sequences in spatial form (see also Cohen Kadosh and Henik, 2007). In other words, visuo-spatial synaesthetes not only experience SNARC effects, but they can consciously report the explicit spatial lay-out on which these SNARC effects rely. These spatial mappings may yet prove to follow from separable earlier stages of magnitude processing (in the spirit of Santens and Gevers, 2008) but they are not the simple pairings of semantically compatible markedness (e.g., left/small). They are direct representations of sequences in space, and their ability to predict the direction of SNARC effects suggests that SNARC in all people may itself reflect a *bone fide* spatial mapping of numbers and other sequences.

But why should visuo-spatial synaesthetes provide any indication about the processing *of the average person*? Even if synaesthetic experiences do validate the synaesthete’s relationship between SNARC and a spatial-mapping of sequences, would this bring us any closer to drawing conclusions about the average person? Put differently, is there independent evidence to suggest that synaesthetes and non-synaesthetes share the same cognitive architectures? The answer appears to be yes. A number of studies show similarities between synaesthetes and non-synaesthetes, suggesting that synaesthetes occupy an extreme end of a shared continuum on which non-synaesthetes also lie. Specifically, the associations of synaesthetes have been shown to rely on processes that are also apparent in non-synaesthetes, with the key difference being the extent to which such associations are available to conscious inspection (for synaesthetes, they are). One example is in the domain of music-colour synaesthesia. Ward et al. (2006) show that synaesthetes tend to see lighter colours from higher pitched sounds, and this same correlation between luminance and pitch is found too in non-synaesthetes making intuitive pitch-colour associations (Ward et al., 2006). In a similar vein, Simner et al. (2005) have shown that both grapheme-colour synaesthetes (who experience colours from letters and/or numerals) and non-synaesthetes share certain preferences for the colours of letters (e.g., for both populations, *a* tended to be red, *s* to be yellow, *x* to be black etc.). Subsequent studies (e.g., Beeli et al., 2008; Smilek et al., 2008) have shown that both synaesthetes and non-synaesthetes map higher frequency graphemes to increasingly luminant colours. In addition, two recent studies (Simner and Ludwig, 2009; Ward et al., in press) suggest commonalities in visual-tactile associations between touch-colour synaesthetes and non-synaesthete controls. In other words, across a range of synaesthesias, independent evidence shows that synaesthetic experiences reflect mechanisms found in all people, albeit to a different level of awareness. This in turn raises the possibility that the consciously experienced spatial sequences in synaesthetes might well indicate a sequence-space mapping in all people.

Cohen Kadosh and Henik (2007) have provided one particularly intriguing suggestion for how synaesthetic visuo-spatial forms might reflect normal processes in the broader population. In their elegant summary of the ways in which visuo-spatial forms (and other synaesthesias) inform cognitive science, Cohen Kadosh and Henick suggest that the idiosyncrasies found in synaesthetic visuo-spatial forms may be indicative of non-uniformities in sequence-space mapping in the general population. Only 65% of the general population demonstrate the classic left-to-right SNARC effect assumed for Western populations (Wood et al., 2006). Intriguingly, this number matches the proportion of left-to-right arrays in *synaesthetic* forms (63% Sagiv et al, 2006; 66% Seron et al., 1992; for numbers 1 to 10). It is possible therefore that (at least some portion of) the ~35% of the general population who fail to show a classical SNARC are working from a mental number line that runs in reverse – or in some other non-standard configuration. (Indeed, Hubbard et al., 2009, this issue, show evidence of individual variation in the direction of significant SNARC effects for non-synaesthete controls.) Importantly, a similar figure (62%) has now also been provided by Eagleman (2009, this issue) in a very large scale assessment of 571 self-reported visuo-spatial synaesthetes. Eagleman's large-scale approach allows him to better identify trends and commonalities in visuo-spatial forms (although his self-reported synaesthetes have yet to be tested for their consistency over time, which is usually required as evidence of genuineness; e.g., Sagiv et al., 2006; Baron-Cohen et al., 1987). Eagleman found that the proportion of synaesthetic forms running left-to-right elicited from his English-Language website was virtually the same figure as is found in the general population showing a left-to-right SNARC effect (Wood et al., 2006). In other words, trends in spatial patterning across both synaesthetes and non-synaesthetes might indicate different degrees of the same phenomenon.

Finally, Eagleman (2009, this issue) takes an important logical step in presenting the proposal in reverse: not only might a number of non-synaesthetes have idiosyncratic (i.e., not left-to-right, or non-linear) forms, but a number of synaesthetes themselves might have entirely *standard* forms. For example, Eagleman's data (if verified) demonstrates that the most common, classifiable explicit synaesthetic sequence-form is a horizontal line, rather than the idiosyncratic loops, ovals, spirals and circles suggested in previous literature. Of the 571 forms that could be classified into an identifiable shape (and 30% could not) the majority were lines of some description (straight lines, bent lines, zigzags) and these comprised 27% of all forms. Eagleman suggests that a preponderance of idiosyncratic forms reported in the synaesthesia literature may have arisen from a recruitment bias – researchers were more struck by idiosyncratic forms and found them more tempting to classify as synaesthetic (see also Price, 2009, this issue; Cohen Kadosh and Henik, 2007). In other words, synaesthetes and non-synaesthetes may be more similar than previously imagined, in that either group might have straight (and left-to-right) forms, and that either may have idiosyncratic forms – with the notable difference lying in the degree of conscious awareness.

Benefits and costs of visuo-spatial forms

A growing body of evidence suggests that synaesthesia may be accompanied by superior scores in certain tasks of cognitive performance. At the same time, other tasks produce inferior scores, and this complex profile of benefits and costs appears to manifest differently depending on the particular variant of synaesthesia. For example, lexical-gustatory synaesthetes (who experience tastes from words) report difficulties maintaining attention when reading (Ward and Simner, 2003), while grapheme-colour synaesthetes show superior memory for colours (Yaro and Ward, 2007) and higher scores in certain tests of creativity (Ward et al., 2008). Grapheme-colour synaesthetes might also demonstrate superior digit memory in certain case-studies (Smilek et al., 2002; but see Rothen and Meier, 2009), but show poor memory for stimuli presented in colours that conflict with their synaesthetic sensations (e.g. difficulty recalling a red *5*, if *5* is synaesthetically green; e.g. Smilek et al., 2002). One recent study (Gheri et al., 2008) has suggested that a sub-set of papers reporting benefits in synaesthetes may suffer from a 'motivational bias': synaesthetes are recruited as a special population and so they simply try harder. For this reason, studies claiming benefits for synaesthetes must now provide 'control' evidence that the same set of synaesthetes also score normally in tests where no exceptional abilities are predicted. In this vein, three papers in this special section investigate the cognitive benefits and costs of visuo-spatial synaesthesia, and demonstrate a systematic profile of assets (in tests where synaesthetic forms are predicted to aid performance), deficits (where synaesthetic forms are predicted to hinder performance) and normal scores (where synaesthetic forms are predicted neither to aid nor hinder).

Ward et al. (2009, this issue) show that synaesthetic visuo-spatial forms are a hindrance in certain aspects of numerical cognition. Ward et al. measured the speeded performance of individuals with synaesthetic number forms versus controls on single-digit multiplication, addition and subtraction. Most people perform subtraction (and to some extent addition) using their mental number line, while they rely more heavily on verbal recall for multiplication (Dehaene and Cohen, 1995; 1997; Lee and Kang, 2002). Ward et al. (2009, this issue) show that visuo-spatial synaesthetes with number forms have speed impairments in mental calculation, but only for multiplication. This suggests that visuo-spatial synaesthetes may be 'over-relying' on their mental number line, to the detriment of speed-of-processing in mental multiplication.

In contrast, Simner et al. (2009, this issue) show that visuo-spatial forms may also come with cognitive benefits. Under timed conditions, time-space synaesthetes with forms for years-within-centuries were significantly more accurate than controls in dating 120 political events (e.g., the release of Nelson Mandela) and cultural events (the timings of film Oscars, and of UK/US hit singles). They also recalled significantly greater autobiographical detail about events in their own life. In other words, synaesthetes' spatial arrangements of time appear to allow for better encoding and/or storage and/or retrieval of information about events in the past. Simner et al. relate these superior abilities to certain 'savant' cases (i.e., individuals with prodigious abilities in one particular domain) and suggest that savantism may arise from the co-incidental co-occurrence of synaesthesia and neurodevelopmental obsessive traits (e.g., from autism; see Baron-Cohen et al., 2007). Simner et al. point to a savant individual with obsessive traits and a time-space visuo-spatial form, who could recall events in time to an extra-ordinary degree (e.g., recalling minutia about days that occurred decades previously; Parker et al., 2006). Simner et al. suggest that this savantism may have resulted from the superior event-recall afforded by the visuo-spatial synaesthesia in combination with a compulsive rehearsal driven by her obsessive traits (see Baron-Cohen et al., 2007, for another case where savantism is traced to synaesthesia).

As well as showing superior performance by synaesthetes in tasks related to the synaesthetic inducer (time), Simner et al. (2009, this issue) also showed superiority in tasks related to the synaesthetic concurrent (visualised space). Importantly, synaesthetes did *not* show superior performance in tasks that were unrelated to their synaesthesia (digit span and reading tests). The visuo-spatial skills identified by Simner et al. came in tasks that rely to a greater or lesser extent on visual memory and imagery (the Visual Patterns Test, Della Sala et al., 1997; Benton's test of 3D Praxis, Benton and Fogel, 1962; VOSP Progressive Silhouettes; Warrington and James, 1991). In a similar vein, Price (2009, this issue) found that visuo-spatial synaesthetes scored superior for visual imagery in self-assessment. Together, these findings suggest that strong general imagery may be a necessary condition to experience synaesthetic spatial forms (see Price, 2009, this issue). However, the precise nature of this ability calls for further inspection: Simner et al. (2009, this issue) found that synaesthetes also out-performed matched controls in mental rotation -- a task ostensibly related to spatial processing -- while Price (2009, this issue) found that self-reported scores in *spatial* abilities were no different from average. This conflict may arise from subtle differences in testing criteria, and raises the question of exactly where synaesthetes' superior visuo-spatial abilities may (or may not) lie. A second possibility is that differences arose in the sampling of visuo-spatial synaesthetes: many of those in Simner et al. had unusually high levels of IQ and education, and although they were matched to non-synaesthetes on these dimensions, it is nonetheless possible that synaesthesia *interacts* with general intelligence in some way that allows different synaesthetes to profit differently from their forms (e.g., some may inspect and/or manipulate them more often, or may better profit from them strategically in other tasks). Clearly, the question of how visuo-spatial forms (and other synaesthesias) impact on general abilities in spatial processing is an area that requires further research (see also Barnett and Newell, 2008; Spiller and Jansari, 2008; Weiss et al., 2005).

Neural roots of visuo-spatial forms

The brains of synaesthetes show increased structural connectivity (Rouw and Scholte, 2007) and studies using functional magnetic resonance imaging (*f*MRI) show that synaesthetic perceptions activate the same neural regions that support veridical perception (e.g., synaesthetic experiences of colour activate the colour-selective region human V4; Nunn et al., 2002; for a review, see Hubbard and Ramachandran, 2005). By extension, Tang et al. (2007) hypothesised that synaesthetic number forms might activate parietal regions that mediate conscious spatial perception. Indeed, they proposed that synaesthetic visuo-spatial forms (and the implicit associations in all people) might be especially encouraged by the close proximity of spatial and numerical centres in parietal areas (see also Hubbard et al., 2005; Ramachandran and Hubbard, 2001). Tang et al. compared patterns of *f*MRI activation for number form synaesthetes and controls, in tasks that treated numbers either cardinally or ordinally (i.e., indicating whether a numeral represents the number of items in a string – e.g., XXX4, or its position within that string – e.g., XX3X). The ordinal condition produced a different pattern of activation in synaesthetes compared to controls, with synaesthetes showing differential activation in the posterior intraparietal sulcus (IPS). This supports the hypothesis that synaesthetic spatial forms may be an exaggeration of normal neural overlap of parietal systems for spatial and ordinal representations (see also Hubbard et al., 2005; Piazza et al., 2006).

This hypothesis rests on the traditional notion of visuo-spatial synaesthesia as linking sequenced units with a set of spatial co-ordinates, but Eagleman (2009, this issue) asks whether the concurrent of a visuo-spatial form in fact has the property of a reified object. In other words, he asks whether visuo-spatial forms represent the *objectification* of sequences, rather than their translation into spatial codes. This hypothesis might find support from synaesthetes' apparent visual, but not spatial superiority in self-report (Price, 2009, this issue; but see Simner et al., 2009, this issue) and would have important implications for understanding the neural roots of synaesthetic forms. Previous accounts (Hubbard et al., 2005; Tang et al., 2008) have pointed to the IPS not only for its processing of cardinal/ordinal information, but also for its role in spatial processing. Eagleman's proposal of synaesthetic forms as reified objects leads him to question whether an additional area of focus might be regions involved in visual object representation, in ventral stream areas such as the inferior temporal lobe.

Eagleman also questions the neural locus of the inducer, suggesting that IPS regions might play a role alongside regions of the middle temporal gyrus. Eagleman makes a subtle distinction between the ordering tasks that have been linked to the IPS, and the type of ordered information required to trigger visuo-spatial forms. Tasks identifying the IPS in ordinal processing (as distinct from numerosity) have required subjects to assess the relative alphabetic ordering of letters (Fias et al., 2007), or to produce months in their canonical versus scrambled order (Ischebeck et al., 2008). Both tasks, Eagleman suggests, focus on the ordering itself, but synaesthetic forms are triggered by *the units* of ordered sequences. Eagleman points to one recent study (Pariyadath et al., 2009) showing that right-lateralised regions of the middle temporal gyrus (rMTG) may be implicated in processing exactly this type of stimulus, and so proposes that this region might be a point of interest for future studies on the neural roots of visuo-spatial forms. Nonetheless, Tang et al. have shown that one key region is the IPS, at least for visuo-spatial synaesthetes with number forms, and Eagleman concedes that both IPS and rMTG may mediate the triggering of synaesthetic forms. For empirical support, we anticipate further future imaging studies of different populations of visuo-spatial synaesthetes.

Classifying visuo-spatial forms

Price's examination of superior imagery skills in individuals with visuo-spatial forms has led him to question whether these forms are themselves merely an extreme form of mental imagery, rather requiring special synaesthetic mechanisms (Price, 2009, this issue). Six out of seven papers in this collection – like the majority of recent studies (e.g., Price and Mentzoni 2008; Seron et al., 1992; Smilek et al., 2007) -- describe the visuo-spatial phenomenon *ipso facto* as a variant of synaesthesia, although the roots of this classification are worth examining. Sagiv et al. (2006) have shown that spatial forms significantly co-occur with archetypal synaesthesias (specifically, grapheme-colour synaesthesia) and that they share the core characteristics of synaesthesia in general: they involve the involuntary and automatic pairing of a trigger stimulus (sequences) with a consistent extra perceptual sensation (a visual/spatial form). Hence, on phenomenological and co-occurrence grounds, it might seem highly reasonable to assume that visuo-spatial forms are a variant of synaesthesia in their own right, and indeed this view has been held since the earliest days of synaesthesia research (e.g. Flournoy, 1893).

Alternatively, visuo-spatial forms might pattern with other (visual) synaesthesias simply because both are perhaps mediated by extreme mental imagery. This view could account for their co-occurrence, and it also has its own historical precedence (e.g., Galton, 1880b). Price (2009, this issue) explores the relationship between visuo-spatial forms and mental imagery by showing not only that visuo-spatial synaesthetes (and I continue to use this terminology for ease-of-exposition) have superior imagery in self-report, but also that non-synaesthetes can mimic the behaviour of visuo-spatial individuals if given appropriate mental imagery instructions. Price found that normal controls emulate the idiosyncratic SNARC behaviour of visuo-spatial synaesthetes if given imagery instructions to generate idiosyncratic forms. In a month-parity task, for example, controls without imagery instructions generated a typical month-SNARC effect (faster left-than-right hand response for early months), suggesting that early months appear on the left-hand side of space (Price and Mentzoni, 2008 re-analysed in Price, 2009, this issue). However, if instructed to imagine months around a clock-face (which now places early month on the *right* side of space), controls now show a reverse-SNARC effect (faster right-than-left hand response for early months). This reverse-SNARC was caused by imagery instructions alone (see also Bächtold et al., 1998) but was equivalent in strength to the reverse-SNARC found in synaesthetes with idiosyncratic forms (i.e., those with early months on the right). This similarity between synaesthetic SNARC effects, and the effects induced by imagery in controls, leads Price to suggest that synaesthetic forms might themselves arise from mental imagery mechanisms. The difference between 'synaesthetes' and controls, now becomes one mediated simply by abilities in imagery: the former population would have imagery abilities that are strong enough to allow for the conscious inspection of their forms. Furthermore, Price suggests that these individuals with high imagery might develop visuo-spatial forms at an early age in order to help categorise the world, and when idiosyncrasies could flourish before the acquired familiarity with social conventions such as calendars, rulers and clocks. Finally, by showing that the experiences of non-synaesthetes can be altered by imagery-instructions, Price's findings speak to recent work that questions whether stimulus-response congruency effects in the general population represent task-specific short term strategies (e.g., Fischer, 2006; Proctor and Vu, 2002).

To end this editorial, I consider a final issue in the classification of visuo-spatial forms. Even where authors have agreed on a classification of synaesthesia, at least ten different names are used here to describe the phenomenon (i.e., *visuo-spatial synaesthesia*, *sequence-space synaesthesia*, *spatial forms*, *synaesthetic spatial forms*, *time-space synaesthesia*, *number-space synaesthesia*, *number forms*, *number-form synaesthesia*, *time lines*, *number lines*). In some cases, authors have simply focussed on one particular sub-variant of the visuo-spatial phenomenon and used terminology accordingly (e.g., *time-space synaesthesia* in Jarick et al., 2009b, this issue).

Other times, a sub-variant term has been used which elsewhere in the literature describes the *full gamut* of forms, in a type of synecdoche (e.g., the term *number forms* is sometimes used to describe all variants of synaesthetic visuo-spatial forms, even those triggered by non-numeric sequences). Given this confusion, one author (Eagleman, 2009, this issue) has called for a terminological clarification, on the basis that better understanding will follow from better naming (see also Simner, 2007 for similar proposals in other synaesthetic domains). Eagleman proposes the term *sequence-space synaesthesia* (*SSS*) for all future studies, because it clearly follows a growing convention of placing the inducer before the concurrent, and because it identifies the true class of inducers (sequences, *per se*, rather than time, or numbers, etc.). Eagleman writes -- in all anticipation -- that 'this sentence hopes to represent the literature's final usage of the term "time space synesthesia"'. To place him in good stead, I have located his paper last in this special section.

Concluding remarks

Seven papers here report the unusual experiences of visuo-spatial synaesthetes who have conscious access to spatial forms for ordinal sequences such as Arabic numerals, hours, days, months, years, and in the case of one individual, for more than 50 different ordered series. These case-studies, group-studies and very large scale studies allow us to see the extent to which visuo-spatial forms share trends and commonalities, and how they might reflect the implicit forms of all people. The synaesthetes described here show spatial response biases in a range of tasks mirroring the lay-out of their idiosyncratic forms, but their effects can be mimicked by imagery-instructions in non-synaesthetes. Synaesthetic forms appear to arise early and automatically, but can be moderated by the modality of the input stimulus. Studies here have also speculated on the neural roots of visuo-spatial forms by considering them either as sets of spatial co-ordinates or as reified objects, and have questioned whether they require only extreme mental imagery or special synaesthetic mechanisms. Finally, these papers show that visuo-spatial forms come with both benefits and costs, but that visuo-spatial synaesthetes perform normally on tasks where their forms do not play a role. Taken together, this body of research might motivate future investigations into this intriguing phenomenon, to determine its own inherent qualities, and the extent to which it might provide an open window on the experiences of all people.

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