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What is the relationship between synaesthesia and visuo-spatial number forms?

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Abstract

This study compares the tendency for numerals to elicit spontaneous perceptions of colour or taste (synaesthesia) with the tendency to visualise numbers as occupying particular visuo-spatial configurations (number forms). The prevalence of number forms was found to be significantly higher in synaesthetes experiencing colour compared both to synaesthetes experiencing taste and to control participants lacking any synaesthetic experience. This suggests that the presence of synaesthetic colour sensations enhances the tendency to explicitly represent numbers in a visuo-spatial format although the two symptoms may nevertheless be logically independent (i.e. it is possible to have number forms without colour, and coloured numbers without forms). Number forms are equally common in men and women, unlike previous reports of synaesthesia that have suggested a strong female bias. Individuals who possess a number form are also likely to possess visuo-spatial forms for other ordinal sequences (e.g. days, months, letters) which suggests that it is the ordinal nature of numbers rather than numerical quantity that gives rise to this particular mode of representation. Finally, we also describe some consequences of number forms for performance in a number comparison task.

It has been suggested that numerical quantity is represented on an analogue scale or a ‘mental number line’ that is spatial in nature (e.g. Dehaene, 1997). Evidence for a spatial (but typically implicit) mental number line in the normal population comes from the

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SNARC effect-the Spatial-Numerical Association of Response Codes (Dehaene, Bossini, & Giraux, 1993). If participants are asked to make number judgements of parity (i.e. odd or even) about the numbers 1–9 then they are faster at making judgements about small numbers (<5) with their left hand and faster at making judgements about larger numbers (>5) with their right hand. Hence, participants perform as if reliant on a spatially-based mental number line running from left to right. In addition, it has been shown that passive viewing of numbers can induce spatial shifts of attention (Fischer, Castel, Dodd, & Pratt, 2003) and that spatial attention deficits can bias numerical judgments (Vuilleumier, Ortigue, & Brugger, 2004).

For most people, the mental number line is implicit insofar as it can only be detected indirectly through behavioural manipulations rather than directly via conscious report. However, a proportion of the population do report consciously visualising numbers in spatial arrays (Seron, Pesenti, Noel, Deloche, & Cornet, 1992). Galton (1880c) documented the first known examples of these ‘number forms’ and introduced this terminology to describe them. In the current study, we examine this phenomenon, and have five aims. The first is a purely empirical question, in which we aim to ascertain the prevalence and characteristics of number forms in the general population. The second aim is to examine whether or not there is a relationship between the tendency to experience anomalous colour sensations with numbers (i.e. number-colour synaesthesia) and the tendency to report number forms. The results may have important theoretical implications for understanding the origin of cross-modal contributions to numerical representation. Our third aim is to consider other ordinal sequences (alphabet, days and months), to address the theoretical question of whether number forms are related to numerical quantity or, more generally, to ordered sets. Next, we provide objective behavioural measures to support these subjective reports. Finally, we consider the phenomenology of number forms in more detail, asking whether the phenomenon should be considered a type of synaesthesia.

A number of studies have attempted to estimate the prevalence of number forms as is summarised in Table 1. Despite discrepancies in these estimates, all point to the fact that number forms are by no means exceptionally rare. Prevalence estimates in children have not been studied in detail but both Galton (1880a) and Peabody (1915) cite a prevalence rate of 25% in male schoolboys. Some of these studies measured the prevalence of ‘visualised numerals’ and, as such, did not make a critical distinction between space and colour. But, a number of studies have drawn attention to the additional presence of number

Table 1
Prevalence estimates for number forms in adult samples

Study	*N*	Overall (%)	Male (%)	Female (%)
(Galton, 1880b)	–	5.0	3.3	6.7
Patrick (1893)[a]	–	16.7	–	–
Flournoy (1893)[a]	370	11.1	–	–
Calkins (1895)	979	–	–	12.0
Phillips (1896–1897)	2009	7.3	6.9	7.7
Seron et al. (1992)	194	14.2	14.6	13.7

[a] Cited in Philips (1896–1897).

forms in people with grapheme-colour synaesthesia (e.g. Baron-Cohen, Wyke, & Binnie, 1987; Collins, 1929; Ginsberg, 1923; Odgaard, Flowers, & Bradman, 1999; Ostwald, 1964; Wheeler & Cutsforth, 1921). These studies raise the possibility that number forms and colour association may have common origins. Others have gone as far as to say that number forms are a type of synaesthesia in their own right, whether coloured or not (Cytowic, 1989; Grossenbacher & Lovelace, 2001). Indeed, the phenomenology of number forms shares many features with synaesthetic colour associations: automaticity, idiosyncrasy, within subject consistency across time, and concreteness of the experience. However, conclusions about the possible association between number forms and synaesthetic experiences of colour are difficult to draw from the small number of single cases that have been reported. We aim to redress this shortfall with a systematic study.

1. Experimental investigation

1.1. The prevalence of number forms in synaesthetes and non-synaesthetes

1.1.1. Method

Participants fell into two broad groups: synaesthetes ($N=114$) and non-synaesthete controls ($N=311$; 88 male, 223 female). The controls were recruited from the University of Edinburgh student population, and each had participated in a stage of screening to ensure they had no synaesthetic experiences of colour, taste, etc. (To avoid circularity we were agnostic about whether number forms should be considered a type of synaesthesia or not). The synaesthetic participants were recruited through our web site (www.syn.ucl.ac.uk). Each reported synaesthetic sensations of either colour or taste in response to linguistic stimuli, including numbers and letters. One hundred of these were colour synaesthetes, of whom 78 were female and 22 were male (a ratio of 3.5:1), and whose mean age was 38.8 years (range = 11–80). The remaining 14 were lexical-gustatory synaesthetes with no experiences of colour (Ward & Simner, 2003; Ward, Simner, & Auyeung, 2005), including 11 females and three males (a female–male ratio of 3.6:1), with a mean age of 40.5 years (range = 27–53). The inclusion of synaesthetes experiencing taste enables us to determine whether there is a relationship between number forms and synaesthesia in the broadest sense, or whether there is a specific relationship with colour.

There were two stages of testing. The first aimed to establish the genuineness of our synaesthete group, using measures of internal consistency. Consistency over time has traditionally been used as a hallmark of genuineness (e.g. Baron-Cohen, Wyke, & Binnie, 1987) and our analyses compared the consistency of our synaesthetes to a group of our controls. Synaesthetes were given a list of letters ($N=26$), numerals ($N=10$), days ($N=7$) and months ($N=12$) and asked to note any synaesthetic associations. This was repeated after a delay of at least 2 months in order to assess internal consistency. These values were compared to those of 62 participants randomly selected from our control group. Forty-eight of these were asked to free associate colours to the same stimuli, and 14 were asked to associate tastes. Both control groups were re-tested at an interval of 2 weeks, and in this way we 'stack the deck' against our synaesthete participants in order to test them more conservatively (e.g. Ward & Simner, 2003).

In the second stage of testing, both synaesthetes and controls were probed for the presence of number forms. All participants were asked to complete a detailed questionnaire examining various aspects of their cognition (e.g. other anomalous experiences, influences on their synaesthesia). For our purposes, we are interested in those questions that asked participants about the presence of forms for numbers, letters, days and months. These questions took the form: 'Do you think about numbers [letters/days/months] as being arranged in a specific pattern in space?' Responses were given on a five point Likert scale (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree). For any response in the affirmative, participants were asked to draw their forms. As with consistency, the reliability of number forms was assessed on a second occasion by asking those with number forms to draw or describe them.

1.1.2. Results

The synaesthetes reporting colour associations were 91.4% consistent over time (SD = 10.1) compared to 33.4% for the control sample (SD = 14.3; $t(146) = 28.47$, $P < 0.001$). Equally, the taste synaesthetes were more consistent (86.2%, SD = 7.2%) than their controls 31.4% (SD = 14.7), and this difference, too, was significant ($t(25) = 10.78$, $P < .001$). These scores show that our synaesthete sample resembles others reported in the literature, and provides objective evidence that they are genuinely different from control participants.

The prevalence of number forms in the control sample and the synaesthetic groups is shown in Fig. 1. Synaesthetes who experience colour are more likely to report the presence of number forms compared to controls who do not experience colour ($\chi^2(1) = 99.86$, $P < 0.001$) and to synaesthetes who experience taste ($\chi^2(1) = 6.99$, $P < 0.01$). There is no difference in the reported proportion of number forms between taste synaesthetes and non-synaesthetic controls ($\chi^2(1) = 1.46$, N.S.), although it is to be noted that the sample size is smaller. These data are consistent with the hypothesis that synaesthesia may enhance the

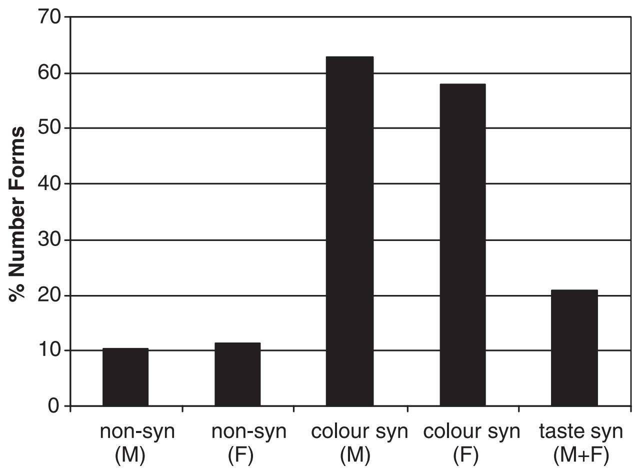


Fig. 1. The prevalence of number forms in synaesthetes and controls who report no colour or taste experiences with numbers or other stimuli (M, male; F, female).

visualisation of number forms, but that the phenomenon is restricted to synaesthetic experiences of colour.

Contrary to the reports of Galton (1880b), but similarly to the findings of Seron et al. (1992), we found that number forms were equally as common in men and women, and that this applied to both colour synaesthetes ($\chi^2(1) = 0.25$, N.S.), and controls ($\chi^2(1) = 0.06$, N.S.). This stands in contrast to the female–male ratio found in other studies of synaesthesia that has been reported to be as high as 5.5–1 (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996), 2.5:1 (Cytowic, 1989) or 3.5:1 in the present study. We return to this point in the general discussion.

The general visuo-spatial characteristics of the number forms exhibited by the synaesthetes and controls are shown in Table 2 with some examples drawn in Fig. 2. The forms were classified according to their overall direction (considering the digits 1–100) and the direction for the first 10 digits. In addition, we tabulated the number of instances in which the form was continuous or discontinuous (i.e. whether there were breaks in the number line in which the line stops and restarts at another position in space) and for the continuous forms, whether they existed as a straight line or contained curves, bends or undulations. Some research has shown that, in the non-synaesthetic population, numbers may be grouped into tens (Nuerk, Weger, & Willmes, 2001). In a follow up interview of a subset of participants with number forms (30 synaesthetes and 12 controls), we also attempted to ascertain whether the number form exists in peripersonal space (e.g. 'starts 5 in. from my face and 1 in. above eye-level') or in imaginal space (or 'mind's eye') that is not specified in coordinates relative to the body. In terms of qualitative characteristics, colour synaesthetes do not differ from controls in terms of direction ($\chi^2(4) = 1.55$, N.S.) or

Table 2
Qualitative characteristics of number forms

Direction	Colour synaesthetes		Controls	
	Overall	Initial	Overall	Initial
	(1–100)	(1–10)	(1–100)	(1–10)
Left–right	70	63	55	68
Right–left	9	5	5	5
Bottom–top	11	18	23	23
Top–bottom	0	0	0	0
Circle/spiral	2	4	0	0
Other	9	11	18	5
	100%	100%	100%	100%
Spatial reference frame	Colour synaesthetes		Controls	
Peripersonal (out-of-body)	37		58	
Imaginal (mind's eye)	63		42	
	100%		100%	
Shape	Colour Synaesthetes		Controls	
Straight line	63		91	
Continuous but not straight	23		5	
Discontinuous	14		5	
	100%		100%	

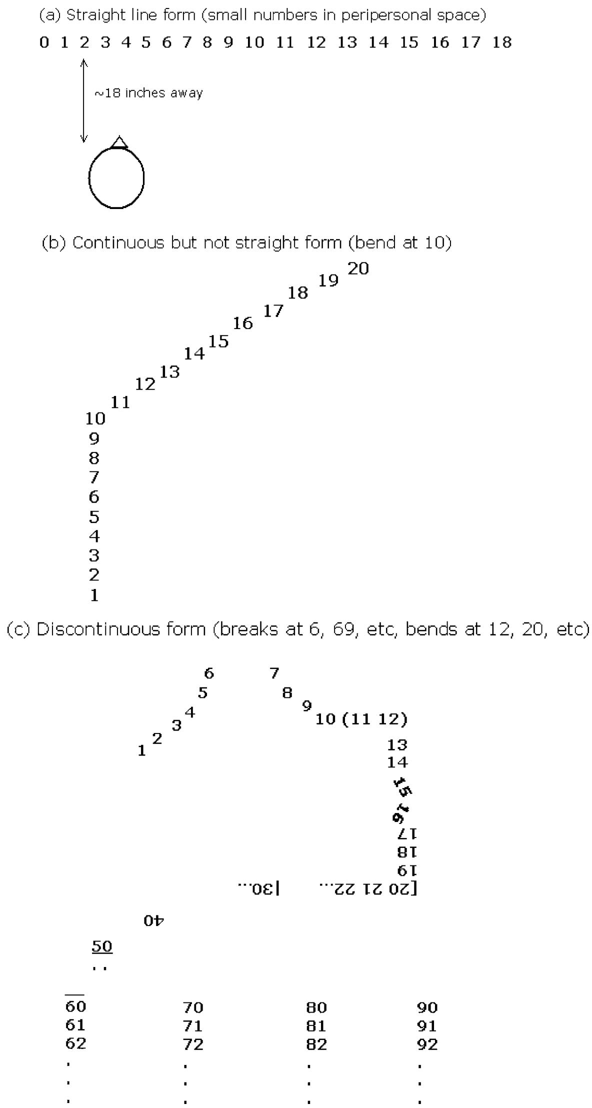


Fig. 2. Examples of number forms from our sample (the colours are not shown).

position in space ($\chi^2(1)=1.64$, N.S.), but there is a trend for synaesthetes to report more convoluted shapes ($\chi^2(1)=6.17$, $P<.05$).

1.2. Are visuo-spatial forms found for other ordinal sequences?

One reason why numbers may be amenable to this type of representation is that they are an ordered set. If it is the ordinal nature of numbers, rather than numerical size, that gives

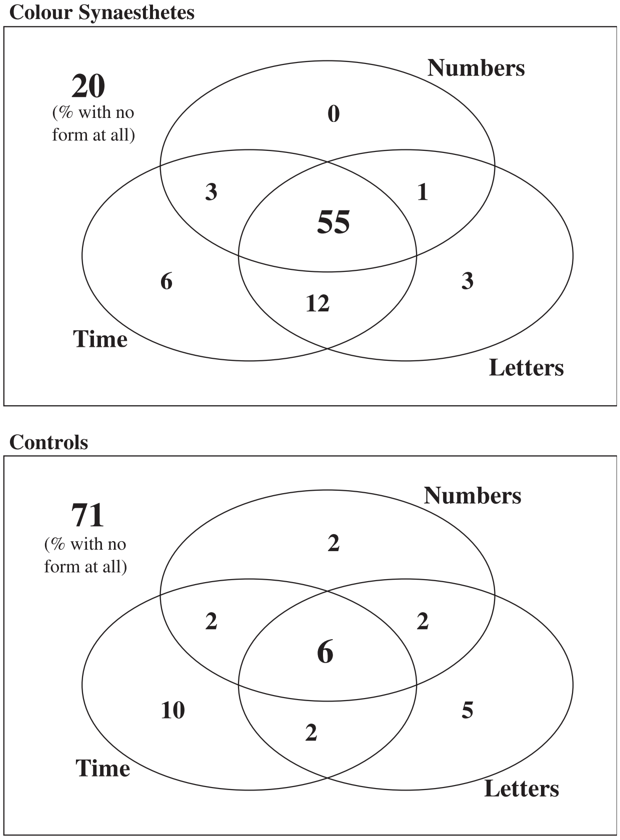


Fig. 3. Venn diagrams showing the prevalence of visuo-spatial forms for numbers, time (=days and/or months) and letters of the alphabet for colour synaesthetes and controls (%).

rise to a visuo-spatial format of representation then we might expect other types of ordinal sequences to be represented in this way (e.g. letters of the alphabet and units of time).[1] Indeed, Gevers, Reynvoet, & Fias (2003) have found a SNARC-like effect in the non-synaesthetic population for months and letters of the alphabet, with earlier months and letters being leftmost. Fig. 3 shows the occurrence of visuo-spatial forms for numerals, letters of the alphabet and time (days and/or months) for our two populations, and provides the following information. First, we see that mental representations of letters and time are also commonly found in synaesthesia, the prevalence rates being 71% (controls = 15.1%) and 76% (controls = 20.0%), respectively. Second, it appears that if a synaesthete has one type of form then there is a very strong tendency for them to also have at least one other type of form (as seen from the high overlap in the Venn diagram). The same holds true for

[1] The most extraordinary case of visuo-spatial forms, to date, is CS (Cytowic, 2002). She reported forms for numbers, months, shoe sizes, height, historical time periods, time of day, TV stations and body temperature, to name a few.

the non-synaesthetes and the synaesthetes that experience taste (the three taste synaesthetes who report number forms all report forms for letters, days and months), the difference being simply that the phenomenon, overall, is less common in these latter groups. We might conclude, then, that visuo-spatial forms are related to ordinal representations rather than number in particular. Indeed similar suggestions have been made with respect to inducers of synaesthetic colour (e.g. Shanon, 1982).

This is in contrast to Walsh's (2003) recent suggestion that space, time, and numbers are linked via a single general magnitude system. While numbers and time are conceptualised in terms of magnitude and order, letters of the alphabet do not carry magnitude information and do not easily fit Walsh's formulation. Nevertheless, the extent to which order and magnitude share common mechanisms is still a matter of debate (e.g. see Turconi, Jemel, Rossion, & Seron, 2004). The present conclusion may accord with an extended framework addressing both magnitude and order.

1.3. Behavioural correlates of number forms

While the findings reported so far suggest that number forms are not confabulatory in origin, we next considered whether the presence of such peculiar spatial representations shows itself with behavioural measures. To document how number forms affect performance we used a spatial congruity paradigm tailored to each participant's number form.

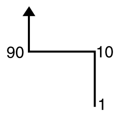
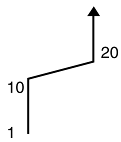
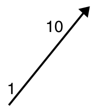
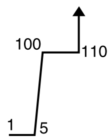
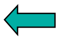
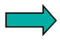
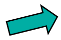
1.3.1. Methods

We tested five individuals with number forms. For each participant, we chose a linear segment (one decade) of the number form from which pairs of numbers were drawn, separated by a distance of either one (e.g. 6,7) or two (6,8). The two numbers were arranged on the screen either congruently with their relative location on the number form, or in the reverse order (an incongruent trial). Response keys were chosen such that their relative location on the British keyboard matched the arrangement of stimuli on the screen (horizontally or diagonally). The experiment was divided into two blocks. In one block participants were required to judge which of the two numbers was larger, and in the other, they decided which one was smaller. Note that by collapsing together the data from the two tasks we avoid a handedness confound. The stimuli were 0.66 degrees tall and presented on the screen (approximately 2.6 degrees of visual angle from fixation) until a response was made. Each block comprised 72 trials (preceded by six practice trials) comprising equal proportions of congruent and incongruent trials. The stimuli were presented in pseudo-random order using E-Prime (www.pstnet.com). Each stimulus was preceded by a fixation cross presented for 500 ms. Table 3 summarizes individual participant's number forms, segment and response keys used, and Fig. 4 contains a sample trial. The results are summarized in (Fig. 5).

1.3.2. Results

Participants responded faster in congruent (684 ms) than incongruent (712 ms) trials [$t(4) = 4.0$, $P < 0.02$]. This trend was observed in all participants. Crucially, the results were significant for S1, whose number form direction is right–left. This is in the opposite

Table 3
Reaction time experiment specification: a schematic drawing of each participant's number form is given, the range of numbers used in the experiment, direction in that range, and response keys used

Participant (age in years)	S1 (28)	S2 (53)	S3 (27)	S4 (55)	S5 (29)
Number form (schematic)					
Range used	21–29	1–9	11–19	1–9	21–29
Direction					
Response keys	G, K	G, K	V, K	M, P	M, O

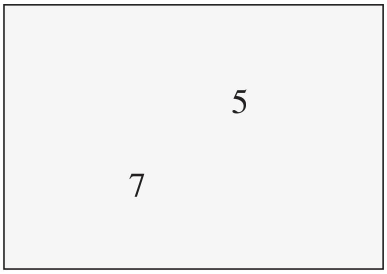


Fig. 4. Sample stimulus used in the behavioural experiments, showing an incongruent trial for a participant with a diagonal number form extending from the lower left to the top right side (S4).

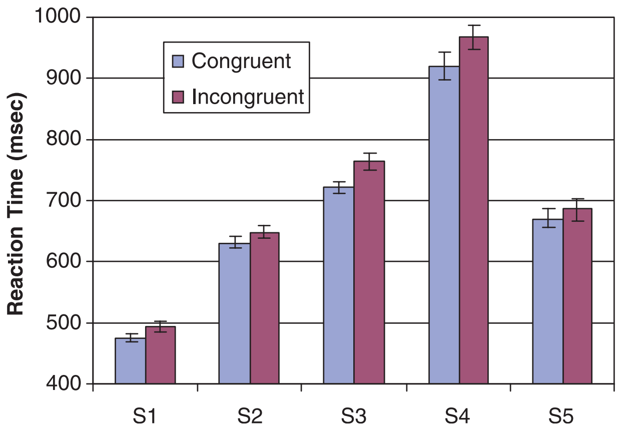


Fig. 5. Reaction times to congruent and incongruent trials.

orientation to most other people with number forms and to that obtained in the general population using the SNARC paradigm. S1 is a native English speaker and does not read in any language written from right to left. Nevertheless, she shows a consistent preference for placing small numbers to the right of larger ones ($t(35) = 2.1$, $P < 0.05$). These results are consistent with individuals' subjective report and suggest that accessing numbers forms may be involuntary.

2. General discussion

There is now a large body of empirical evidence to suggest that aspects of numerical representation are visuo-spatial in nature (recent reviews of numerical spatial interactions are provided by Fias & Fischer, 2005; Hubbard, Piazza, Pinel, & Dehaene, 2005). Evidence for this comes from studies of number-space response compatibility (Dehaene, Bossini, & Giraux, 1993) and studies of spatial attention (Fischer, Castel, Dodd, & Pratt, 2003; Zorzi, Priftis, & Umilta, 2002). Additionally, a proportion of the population consciously report visualising numbers in a spatial array. Anecdotal reports have previously suggested that synaesthetes often report such 'number forms', and our study documents this empirically. It shows also that a higher rate of number forms in synaesthetes is related specifically to those synaesthetes who report associations of colour. The fact that synaesthetes are not more likely to report other unusual phenomenon (including déjà vu and out-of-body experience; Simner et al., in prep; also Rich, Bradshaw, & Mattingley, in press) together with the fact that taste synaesthetes do not report a high prevalence of number forms, suggests that these results are not merely a bias to report atypical experiences.

2.1. Why are synaesthetes more likely to report number-forms?

One explanation for the higher prevalence of number forms in colour synaesthetes is that there may be an interaction between the general tendency to represent numbers in spatial codes (present in us all) and, in a few individuals, the tendency for numerals to evoke spontaneous colour experiences. That is, the presence of colours could increase awareness of the number form that in most other individuals is only implicit. How might this occur? A relatively parsimonious account is that existing spatial codes for numbers are used as default locations at which the corresponding synaesthetic colours are seen. Alternatively, synaesthetes may have better access to material that would not otherwise be available for conscious report, as suggested by Cytowic (e.g. 2002). As such, the study of synaesthesia may be used to reveal important cross-domain mechanisms that operate in us all. Given that most people do not report explicit number forms it is very hard to ascertain the precise configuration of their putative mental number line, except in the broadest of terms (e.g. that they tend to go from left to right-as do those of the synaesthetes). One shortfall of this idea is that it does not account for the tendency of synaesthetes' number forms to be slightly more convoluted.

Another explanation for the co-occurrence of numbers forms and grapheme-colour synaesthesia is that number forms are a type of synaesthesia in their own right (e.g.

Grossenbacher & Lovelace, 2001; Ramachandran & Hubbard, 2001). On purely phenomenological grounds this might seem reasonable and, indeed, this view has been accepted within synaesthesia research since the 19th century (e.g. Flournoy, 1893). We will return to the phenomenology of number forms shortly.

How inclusive the definition of synaesthesia should be is not an empirical question. Instead, strong evidence for a common mechanism underlying synaesthesia and number forms should also be considered. Could number forms share a common genetic and neurocognitive basis? At first glance, the strong female bias reported in earlier synaesthesia studies seems to be at odds with the absence of gender bias in number form prevalence rates seen here and in other large-scale studies (e.g. Seron et al., 1992). The former have been explained by an X-linked genetic mechanism (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996; Ward & Simner, 2005). There is also a suggestion that number skills could be X-linked from genetic disorders known to lie on this chromosome (e.g. Bruandet, Molko, Cohen, & Dehaene, 2004). Although Galton believed that number forms ran in families, the mode of inheritance of number forms has never been established or investigated. If one wishes to argue that number forms are a type of synaesthesia one would need to entertain either of two possibilities: either the reported female bias is an artefact (e.g. of relying on self-referred samples) and/or number forms arise from a different causal mechanism. In a recent survey of synaesthesia in two populations, we found that no evidence for a notably higher prevalence of synaesthesia in females (Simner et al., submitted). It is therefore, plausible that synaesthesia and number forms have the same cause. If this is the case, it should be possible to inherit synaesthesia from a parent with number forms only (or vice versa). At present, we have only anecdotal evidence consistent with this.

2.2. The phenomenology of number forms: similarities to synaesthesia

Let us now consider in more detail the key features of synaesthesia (e.g. Cytowic, 2002; Sagiv, 2004) and whether the phenomenology of number forms can be described in similar terms.

Number forms, like synaesthesia, are present from childhood and consistent across time within an individual. Number forms often involve a vivid perceptual experience (e.g. the number is actually seen, printed at its typical location) however, in a minority of cases, the experience is not visuo-spatial but rather a pure spatial one. This sense of space feels very real to the person experiencing it. We see no reason why this should not be considered a perceptual experience any less than proprioception, for example. These individuals know the precise locations of numbers in peri-personal space but these are not accompanied by visual imagery. Interestingly, such pure spatial codes may include locations outside the visual field (e.g. behind the individual possessing them). Cytowic's (2002) description of synaesthetic experience as spatially extended obviously applies to number forms too, whether visuo-spatial or pure spatial.

Another issue is automaticity. Synaesthetic experience is automatic and for the most part, not subject to voluntary control.[2] Synaesthetes cannot think about a number without

[2] Attention to the inducing stimulus could modulate synaesthesia (Sagiv, Heer, & Robertson, in press).

experiencing the corresponding colour. Similarly, those with number forms claim they cannot entertain a numeric concept without accessing these spatial codes. Thus, accessing the spatial code appears at least mandatory for comprehension. However, to describe this access as automatic is somewhat oversimplified. A further distinction can be made with respect to the perceived effort associated with shifts of attention in this 'number space', particularly to locations far from the default origin or viewpoint. Spontaneous comments made by individuals we tested suggest that when presented with a large number, some of them see their number form automatically scrolling in front of them. Others, however, perceive it as an effort required on their part: They need to 'bring it over here' or 'go over there'. While we have yet to explore this question systematically in the entire sample, further research will determine whether such descriptions represent genuine individual differences in the nature of these representations and what might be the role of action in linking numbers and space in the case of number forms (c.f. Rossetti, Jacquin-Courtois, Rode, Ota, Michel and Boisson, 2004).

Synaesthetic correspondences tend to be idiosyncratic. Although some trends do exist (e.g. Rich, Bradshaw, & Mattingley, in press), synaesthetes rarely agree about the colours of more than a few graphemes. Individuals with number forms agree about the shape and overall direction more often (the majority are straight lines and overall direction left to right), however, the more convoluted forms are largely idiosyncratic.

Synaesthetes often feel strongly about grapheme-colour correspondences. While the sense of certitude is probably shared by individuals with number forms (with respect to number locations), it is unclear that there is a strong affective component in the case of a spatially incongruent number presentation for example. Since this is one of the least explored aspects of synaesthesia, we postpone further discussion until adequate data are available.

In sum, to the extent that comparisons between colour experiences and a spatial sense are possible, it seems that number forms do share much in common with synaesthesia.

2.3. *The functional significance of number forms*

Our study provides certain clues as to the functional significance of this type of representation (i.e. why numbers should be represented in this way). Number forms tend to co-occur with forms for other ordinal sequences such as days, months and the alphabet, which suggests that it is the ordinal nature of numbers rather than numerosity that results in this mode of representation.[3] Crucially, this raises doubts about whether the mental number line plays an essential role in calculation and numerical ability.[4] The only patient known to have a 'defective' number form as a result of brain damage also became dyscalculic (Spalding & Zangwill, 1950). However, this case could potentially be

[3] A neuropsychological dissociation between these two types of number meaning was reported by Delazer and Butterworth (1997). They report an acalculic patient with impaired cardinal numbers but spared ordinal numbers. He could say what number came after 8, but not the answer to $8+1$. The reverse dissociation is reported by Turconi and Seron (2002).

[4] Although time-planning may be considered analogous to calculation, it is unclear that any form of calculation takes place using letters of the alphabet.

interpreted as two coincidental deficits, rather than a deficit in one (number form) causing a deficit in another (calculation). Our research also raises the question of whether concepts such as calendar time are, in some respects, functionally equivalent to numbers. Days are grouped in to weeks, months are grouped into years, number units (0–9) are grouped into bases and the patterns repeat recursively. There is a general tendency to map orderable concepts or precepts in a spatial way (e.g. musical pitches, Rusconi, Kwan, Giordano, Umiltà, & Butterworth, in press).

The fact that the left parietal lobe is involved in numerical representation and also certain aspects of space representation (particularly of body space) may be important for accounting for the origin of number forms. Many of the number forms in both our synaesthetes and controls do report their number forms to be in peri-personal space suggesting that numbers, for such people, are a component of a modified body schema. Indeed, space, and the body, may be convenient placeholders during the development of counting and number comprehension (Butterworth, 1999). Perhaps, the use of concrete visuo-spatial representations reduces the computational burden of holding in mind the magnitude of collections, and this ability has been evolutionarily selected for.

It is not clear why some colour synaesthetes do not visualise a number form. One speculation is that for some synaesthetes, colours arise from an Arabic numeral level of representation (in the left fusiform) whereas for others, their colours may arise from the number concepts themselves (in the left parietal lobe) (Ramachandran & Hubbard, 2001). This is an empirical question that we are currently exploring. The fact that synaesthetes experiencing tastes are no more likely to report number forms than non-synaesthetes is consistent with the idea that all of these phenomena involve a local difference in the functional organisation of the cerebral cortex. It is interesting to note that an apparently rare mode of cognition-synaesthesia—may provide a unique window into the mechanisms by which we all process and represent numbers.

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