ELSEVIER

Varieties of grapheme-colour synaesthesia: A new theory of phenomenological and behavioural differences

Jamie Ward *, Ryan Li, Shireen Salih, Noam Sagiv

Department of Psychology, University College London, Gower Street, London WCIE 6BT, UK

Abstract

Recent research has suggested that not all grapheme-colour synaesthetes are alike. One suggestion is that they can be divided, phenomenologically, in terms of whether the colours are experienced in external or internal space (projector–associator distinction). Another suggestion is that they can be divided according to whether it is the perceptual or conceptual attributes of a stimulus that is critical (higher–lower distinction). This study compares the behavioural performance of 7 projector and 7 associator synaesthetes. We demonstrate that this distinction does not map on to behavioural traits expected from the higher–lower distinction. We replicate previous research showing that projectors are faster at naming their synaesthetic colours than veridical colours, and that associators show the reverse profile. Synaesthetes who project colours into external space but not on to the surface of the grapheme behave like associators on this task. In a second task, graphemes presented briefly in the periphery are more likely to elicit reports of colour in projectors than associators, but the colours only tend to be accurate when the grapheme itself is also accurately identified. We propose an alternative model of individual differences in grapheme-colour synaesthesia that emphasises the role of different spatial reference frames in synaesthetic perception. In doing so, we attempt to bring the synaesthesia literature closer to current models of non-synaesthetic perception, attention and binding.
© 2006 Elsevier Inc. All rights reserved.

Keywords: Synaesthesia/synesthesia; Space perception; Binding; Attention; Colour/color; Grapheme

1. Introduction

In recent years, the main focus of synaesthesia research has shifted away from demonstrations that the reported phenomena are genuine (although this clearly remains crucial) towards integrating various empirical findings within an explanatory framework. One difficulty in putting forward a coherent explanatory framework for synaesthesia is that there are a number of findings in the literature that appear to be mutually inconsistent with each other. For example, some studies suggest that synaesthesia can be induced pre-attentively (e.g. Smilek, Dixon, Cudahy, & Merikle, 2001) whereas other studies do not (e.g. Mattingley, Rich, & Bradshaw, 2001). At

present, the source of these inconsistencies is unclear. However, a likely candidate for explaining the inconsistencies is in terms of qualitative individual differences between synaesthetes that, otherwise, have the same pairing of inducers (e.g. graphemes) and concurrent experiences (e.g. colour). The aim of the present study is to examine these individual differences further in order to develop a new explanatory framework of one particular type of synaesthesia; namely, grapheme-colour synaesthesia.

At present, there are two main accounts of individual differences in grapheme-colour synaesthesia. One account, termed the projector–associator distinction, is motivated by different phenomenological reports of synaesthetes (Dixon, Smilek, & Merikle, 2004; Smilek & Dixon, 2002). Some synaesthetes report that when viewing visual graphemes their synaesthetic colours exist in external space and are superimposed on the text. These have been termed projector synaesthetes. Others report experiencing colours, when viewing graphemes, that appear in their "mind's eye" or an internalised space. These have been termed associator synaesthetes. It is to be noted that not all phenomenological reports map exactly on to this dichotomy. For example, some synaesthetes experience colours in external space but the colours "float" at some fixed distance from their body rather than exist "out there on the page". It remains an open issue as to how these synaesthetes should be characterised. An alternative account has been termed the higher–lower distinction, and is motivated by differences in the level of representation of the inducing stimulus (Ramachandran & Hubbard, 2001b). In the terminology of Grossenbacher and Lovelace (2001) all types of synaesthesia have two essential elements: a stimulus that triggers the synaesthesia (an inducer) and the synaesthetic experience itself (the concurrent). Whereas the projector–associator distinction refers to differences in the concurrent, the higher–lower distinction refers to differences in the inducer. In particular, higher synaesthesia is assumed to reflect a conceptual level of induction (e.g. the meaning of a digit) whereas lower synaesthesia is assumed to reflect perceptual processing (e.g., of the digit's form). Taking the validity of these distinctions at face value (for now) and assuming them to be orthogonal, this generates four different varieties of grapheme-colour synaesthesia. However, an alternative proposal is that these two distinctions are the same; such that all projector synaesthetes are lower synaesthetes and all associator synaesthetes are higher synaesthetes (Dixon & Smilek, 2005; Dixon et al., 2004). This study will empirically assess this suggestion, along with several others. Before doing so, it is important to consider the evidence put forward so far for these distinctions.

1.1. The projector–associator distinction

Dixon et al. (2004) reported an objective measure that reliably discriminated between the 5 projector and 7 associator grapheme-colour synaesthetes that they tested. Their task was a variation on the synaesthetic version of the Stroop paradigm that has now been used in many other studies (e.g. Mattingley et al., 2001; Mills, Boteler, & Oliver, 1999). In the standard form of these tasks, the synaesthete must name the actual colour in which a digit or letter is presented and ignore their synaesthetic colour. The synaesthetic colour can either be congruent with the actual colour (e.g. a red "A" where their synaesthetic colour for "A" is red) or incongruent with it (e.g. a green "A" where their synaesthetic colour for "A" is red). Synaesthetes are slower in the incongruent relative to congruent condition implying that their synaesthetic colour is automatically elicited even when irrelevant to the task. Dixon et al. (2004) compared the standard version of the task with one in which the stimuli are the same but in which the instructions are reversed such that synaesthetes are required to name their synaesthetic colour and ignore the real colour. Projector synaesthetes were faster at naming synaesthetic colours relative to real colours, but associator synaesthetes were faster at naming real colours relative to synaesthetic ones (a double dissociation). Their explanation of this is that projected colours are more automatic because they reflect reciprocal activation between regions involved in grapheme recognition and colour processing early in the visual stream, whereas associator synaesthetes have links with more conceptual aspects of colour and vision that arise later. They do, however, also discuss a number of alternative explanations. For example, the reason why associator synaesthetes may be slower at naming their synaesthetic colour could be because their synaesthetic colour is, by definition, in a different spatial location to the attended grapheme. Naming their synaesthetic colour would require a shift in attention from the grapheme location to the colour location. The reason why projector synaesthetes are faster at naming their synaesthetic colour relative to actual colours (the reverse dissociation) is harder to account for but may reflect that fact that their synaesthetic colour occludes or is more vivid than the actual colour.

A central aspect of their account of projector synaesthetes is the notion of interactive activation between grapheme recognition and colour processing such that both occur in parallel. Early analysis of the grapheme may trigger early colour processing before full grapheme recognition has taken place. Moreover, this early colour processing may bias grapheme recognition itself. In support of this they show that in their projector, C, it is harder to identify a synaesthetically blue grapheme presented in black text against a blue background relative to when the synaesthetic colour is different from the background (Smilek et al., 2001) and that a briefly presented grapheme is less susceptible to object substitution masking (Wagar, Dixon, Smilek, & Cudahy, 2002). The authors claim that colour processing biases grapheme recognition and, moreover, that synaesthetic colours can be induced before conscious recognition of the grapheme (i.e. contrary to Mattingley et al., 2001). However, the latter claim may be too strong given that the behavioural measure used in both of these tasks was explicit identification of a grapheme. In both of these tasks, the grapheme was available to conscious report and so it is unclear from these studies whether conscious (and unbound) perceptions of colour can occur in situations in which the grapheme cannot be reported.

Other studies in a similar vein have measured the visual search time to (consciously) detect a grapheme in an array of distractor stimuli. If the target, presented in a text colour that is neutral, can be detected quickly on the basis of its synaesthetic colour this suggests that the colour is available early enough to elicit exogenous orienting (rather than endogenous attention based on serial search). Some studies have reported that projectors are faster/more accurate at detecting the target (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Smilek et al., 2001, Smilek, Dixon, & Merikle, 2003) whereas other studies have not (Edquist, Rich, Brinkman, & Mattingley, 2006; Sagiv, Heer, & Robertson, 2006a). The conditions in which the facilitation is found differs from the comparable situation in which non-synaesthetes are assumed to detect stimuli on the basis of pre-attentive colour recognition. In synaesthetes, it has been suggested that the location of the target relative to fixation is important (Laeng, Svartdal, & Oelmann, 2004) and that the effect is only found if the distractors also elicit a synaesthetic colour (Palmeri et al., 2002; Sagiv et al., 2006a). The latter has been used to argue that facilitation in synaesthetic visual search is due to efficiency of rejecting distractors using colour, rather than 'pop out' of the target on the basis of its colour. Indeed, the response times to detect a target do show a characteristic increase with number of distractors that is indicative of serial rather than parallel search. Although a full resolution of this debate is lacking, it is reasonable to conclude that the evidence in favour of projector synaesthetes having pre-attentive perception of the colour of yet-to-be-perceived graphemes is not as straightforward as first assumed.

1.2. The higher–lower distinction

The mechanistic explanation of the difference between projectors and associators put forward by Dixon et al. (2004) is similar to the distinction between higher and lower synaesthetes independently put forward by Ramachandran and Hubbard (2001b). Turning next to the higher–lower distinction, it is perhaps harder to classify synaesthetes according to this dimension because it is based upon theoretical assumptions about how conceptual processing may reveal itself in synaesthesia rather than pre-theoretical phenomenological reports. In their original paper, Ramachandran and Hubbard (2001b) considered a number of factors that may potentially discriminate between the two varieties. Firstly, some synaesthetes report the same colour for different stimuli with the same meaning (e.g. the digit "4", the Roman numeral "IV", and four dots). Secondly, higher synaesthesia may be particularly associated with ordinal sequences. This is because ordinality is a semantic-level property. Thus, days of the weeks and months of the year may be coloured differently from that expected from their graphemic composition and the sequences may exist in spatial 'forms' as reported by Galton (1880b, 1880a) and more recently by Sagiv, Simner, Collins, Butterworth, and Ward (2006b). In addition to these behavioural indicators, Ramachandran and Hubbard (2001b) speculate on some neuroanatomical differences. They suggest that lower synaesthesia reflects cross-activation between the fusiform region involved in grapheme recognition and the colour area V4, whereas higher synaesthesia may reflect cross-activation between the angular gyrus (implicated in numerical cognition and spatial processing) and the superior temporal sulcus (which they cite as a secondary colour area).

In order to test their theory, Hubbard, Arman, Ramachandran, and Boynton (2005a) observed individual differences in brain-behaviour correlations in grapheme-colour synaesthetes. In the fMRI phase of their study

the brain activations in a number of visual regions were contrasted when viewing black on white graphemes (that elicit a colour) versus false fonts (that do not). It was found that whilst activity in area V4 was reliable across synaesthetes, activity in lower visual regions (e.g. V1) differed greatly between synaesthetes. Moreover, activity in V4 correlated with behavioural performance on a task of visual crowding performed outside the scanner. In this task, participants are briefly presented with a grapheme presented in the periphery (left or right side) and surrounded by a distracting grapheme. The task of the participants was to identify the briefly presented grapheme in the centre of the distractor graphemes. They suggest that differences in the ability to perform this task map on to the lower/projector (better performance, more V4 activity) versus higher/associator distinctions (average performance, less V4 activity). There was anecdotal report from one lower/projector synaesthete (JAC) that he often experienced a colour and used this to infer the identity of the grapheme. Taken at face value, this seems convincing evidence for pre-attentive synaesthetic induction of colours (Treisman, 2004). This claim is explored further in the present study.

The present study has a number of aims. Firstly, we aim to show that it is possible to behaviourally distinguish between projectors and associators using tasks based on those of Dixon et al. (2004) and Hubbard et al. (2005a, 2005b). One recent study has challenged this claim and suggested that these distinctions are unstable and/or do not produce reliable behavioural differences (Edquist et al., 2006). Secondly, we will consider whether the projector–associator distinction is maps on to the higher–lower distinction, or whether these are orthogonal distinctions. Finally, we present a new model of grapheme-colour synaesthesia that accounts for the existing data and makes novel predications.

2. Case descriptions

The experiments below contrast the performance of 14 grapheme-colour synaesthetes, 7 of whom are classified as projectors and 7 of whom are classified as associators (or 'non-projectors'). The background details of the participants are summarised in Table 1. We classified synaesthetes as projectors if the colours elicited during reading were subjectively localised on the text itself, rather than presence of colours in external space

Table 1
Background details of synaesthetes

	Age	Sex	Grapheme-colour Synaesthesia	Consistency % (test–retest time)	Consistency (number and type of stimuli tested)
VE	22	F	Projector	100 (4 months)	$N = 36$; letters, digits
JH	56	M	Projector	96 (6 months)	$N = 55$; letters, digits, days, months
TD	36	M	Projector	100 (2 months)	$N = 36$; letters, digits
SN	34	F	Projector	100 (16 months)	$N = 36$; letters, digits
BJ	58	M	Projector	86 (2 months)	$N = 36$; letters, digits
ZV	18	F	Projector	100 (4 months)	$N = 55$; letters, digits, days, months
YR	26	F	Projector	100 (5 months)	$N = 55$; letters, digits, days, months
Mean	35.7	—	—	96 (5.7 months)	—
MKS	37	F	Associator (external screen)	100 (3 months)	$N = 86$; letters, digits, days, months, words
MOM	22	M	Associator (internal screen)	82 (7 months)	$N = 55$; letters, digits, days, months
SM	34	F	Associator (knows colour)	100 (18 months)	$N = 67$; letters, digits, days, months, words
AA	37	F	Associator (internal screen)	100 (12 months)	$N = 55$; letters, digits, days, months
JR	60	F	Associator (knows colour)	96 (20 months)	$N = 55$; letters, digits, days, months
EP	35	F	Associator (external screen)	100 (3 months)	$N = 29$; digits, days, months
TA	23	F	Associator (internal screen)	86 (7 months)	$N = 55$; letters, digits, days, months
Mean	35.4	—		95 (10.0 months)	

per se. For present purposes, we operationally define associators as 'not projectors' but we offer a new taxonomy of differences in phenomenology in Section 4. Two synaesthetes classed as non-projectors, MKS and EP, reported colours in external space. EP perceives her synaesthetic colours on a screen located above her right shoulder (behind her normal field of view), whereas MKS reports her colours on a screen 'in space' located a fixed distance from her face and in front of her normal reading distance. Both synaesthetes experienced colours on this screen when listening to speech as well as reading, suggesting that the location of the colour is not determined by whether graphemes are visually perceived. It will be shown that behaviourally they tend to perform like associators who perceive colours internally.

The internal consistency of the synaesthetes was assessed over an average period of 7.8 months (range = 2–20 months), and the mean consistency was 96% (range = 82–100%). This was assessed using verbal colour descriptions. A previous sample of non-synaesthetic controls was found to have a consistency of 35.5% (SD = 13.8) when assessed over a 2 week test–retest period (reported in Simner et al., 2005). Each synaesthete lies beyond a 2 standard deviation cutoff ($P < .05$) based on the control distribution of scores. The experiments reported later (e.g. Stroop interference) provide further evidence for the authenticity of these cases.

Our initial classification of synaesthetes was based on the subjective locations of their synaesthetic colours when viewing visual graphemes (i.e. the projector–associator distinction). Given the suggestion that this classification may collapse on to the higher–lower distinction, we assessed the extent to which the behavioural characteristics expected of higher and lower synaesthetes are found in projector and associator/non-projector synaesthetes. In particular, we determined whether colours were elicited from black on white dice patterns ($N = 6$) and whether the colour of written number names ($N = 10$; e.g. ONE, FIVE) are the same as for digits (e.g. 1, 5). We also determined whether or not spatial forms exist for sequences (numbers, days, weeks, letters) and the spatial location of these forms (mind's eye versus outside the body). It is to be noted that the spatial forms were internally generated rather than elicited from visual presentation of stimuli. As such there was no scope for binding synaesthetic colours to a visual inducer, but it was nonetheless possible to experience colours in external space. In addition, the colours associated with days of the week and months of the year were noted (when they occurred) and we attempted to characterise whether the colours were derived from graphemic properties of the word (e.g. first letter, first vowel) or whether the colour was a word-level property of the stimulus (for other examples of this approach see Ward, Simner, & Auyeung, 2005). The results of these questions are summarised in Table 2. Whilst we were not able to empirically test each and every claim, we were able to assess their reliability over time. Most of these questions (except the dice pattern) were included on the original questionnaire distributed to participants, and they were asked these questions again at the retest many months later. Some of these claims have been followed up elsewhere (e.g. we have assessed TD's synaesthesia for dice patterns and finger counting; Ward, Butterworth, & Sagiv, in preparation).

The summary in Table 2 highlights the importance of individual differences amongst grapheme-colour synaesthetes. Some synaesthetes showed the characteristics that Ramachandran and Hubbard (2001a, 2001b) would ascribe to higher synaesthetes. For example, BWJ has the same colours for digits, dice patterns and written number words. Moreover, days and months have colours that do not derive from the graphemic constituents. Other synaesthetes have predominantly lower characteristics according to the criteria of Ramachandran and Hubbard (2001a, 2001b). For example, SM does not experience colours for dice patterns and all words (including number names, days, months) are coloured by graphemic constituents. However, there is little to suggest that these traits are related in any way to the projector–associator distinction. It appears as if these may be orthogonal dimensions rather than one and the same dimension as has recently been stated. Moreover, it may be possible to exhibit characteristics of 'higher' synaesthesia in one respect but not another. The presence of number forms is certainly not a unique feature of being an associator, and the location of the spatial forms (externally or internally) does not correspond well to whether or not colours appear bound to the page when viewing text.

The remaining experiments are extensions and replications of previous studies that have been claimed to be sensitive either to the projector–associator distinction, the higher–lower distinction or both. Experiment 1 is based on the Stroop experiment of Dixon et al. (2004). Experiments 2 and 3 are based on the visual crowding experiment of Hubbard et al. (2005a, 2005b). In Section 4, we will present a revised model of grapheme-colour synaesthesia that integrates a variety of findings.

Table 2
Higher' and 'lower' characteristics of projector and associator synaesthetes

Participant	Colours for number concepts? Higher = yes, Lower = no		Spatial Forms? Higher = yes, Lower = no (location in space)				Are colours for words derived from graphemic constituents? Higher = no, Lower = yes	
	Dice	Number names	Numbers	Days	Months	Letters	Days	Months
Projectors								
VE	L	L	L	H (internal)	H (external)	H (external)	L	L
JH	L	L	H (external)	H (external)	H (external)	H (external)	L	L
TD	H	L	H (external)	H (external)	H (external)	H (external)	H	H
SN	L	L	H (external)	H (external)	H (external)	H (external)	H	H
BJ	H	H	H (internal)	H (internal)	H (internal)	H (internal)	H	H
ZV	L	L	H (internal)	H (internal)	H (internal)	H (internal)	L	L
YR	H	L	H (internal)	H (internal)	H (internal)	H (internal)	H	H
Associators								
MKS	H	L	L	H (external)	H (external)	L	L	L
MOM	H	H	L	L	L	L	L	L
SM	L	L	L	H (internal)	H (internal)	L	L	L
AA	L	H	H (internal)	H (internal)	H (internal)	H (internal)	H	H
JR	L	H	L	H (external)	H (external)	L	H	H
EP	L	H	L	H (external)	H (external)	H (external)	L	L
TA	L	H	L	L	L	L	H	H

The presence of the following 'higher' characteristics was assessed: whether dice patterns are coloured the same as corresponding digits; whether number names (e.g. FIVE) are coloured the same as corresponding digits (e.g. 5); whether spatial forms are found (and their location in space); and finally whether days and months have colours that are unrelated to their graphemic constituents. There is no obvious link between associators and higher traits, or between projectors and lower traits.

3. Experimental investigation

3.1. Experiment 1: Synaesthetic stroop for veridical versus photism naming

This experiment is based on that reported by Dixon et al. (2004). The aim is to establish whether the differences between veridical colour naming and photism naming extend to the present sample of projectors and associators, thus providing one objective correlate of their subjective reports.

3.1.1. Participants

The 14 synaesthetes previously described took part. Given that the hypothesis concerns between-group differences amongst synaesthetes, no control group was tested.

3.1.2. Methods

The stimuli consisted of 8 different graphemes (letters and digits) that were displayed in 64 trials. For half of the trials, the grapheme was presented in a colour congruent with their synaesthesia and for the remaining half of the trials it was presented in a colour incongruent with their synaesthesia. In a pre-test, synaesthetes had been asked to choose an exact colour from an RGB palette if their verbal description was ambiguous (e.g. bluey grey). Incongruent grapheme-colour associations were formed by reassigning the same palette of colour used in the congruent condition to a different grapheme. The 64 trials were randomised. Each trial began with a central fixation (+) presented for 1000 ms. Following this, the grapheme was displayed against a mid-grey background. The stimulus remained until the participant made a response into a microphone. The experiment was repeated on two successive occasions but with the instructions varying on each occasion. Synaesthetes were required to name either their synaesthetic colour and ignore the veridical colour, or to name the veridical colour and ignore their synaesthetic colour. The order of the instructions was counter-balanced across synaesthetes.

3.1.3. Results and discussion

Errors and trials in which the microphone was inappropriately triggered (e.g. because the response was too quiet to be detected) were excluded from the reaction time analysis. Following this initial trimming, outlying reaction times (>3 standard deviations from the mean of each participant) were also excluded. The results are summarised in Fig. 1. A $2 \times 2 \times 2$ ANOVA was conducted on group (projector v. associator), congruency (congruent v. incongruent) and task-set (synaesthetic colour v. veridical colour). There was a significant main effect of congruency ($F(1,12) = 24.66$, $P < .001$) consistent with previous demonstrations of Stroop-like
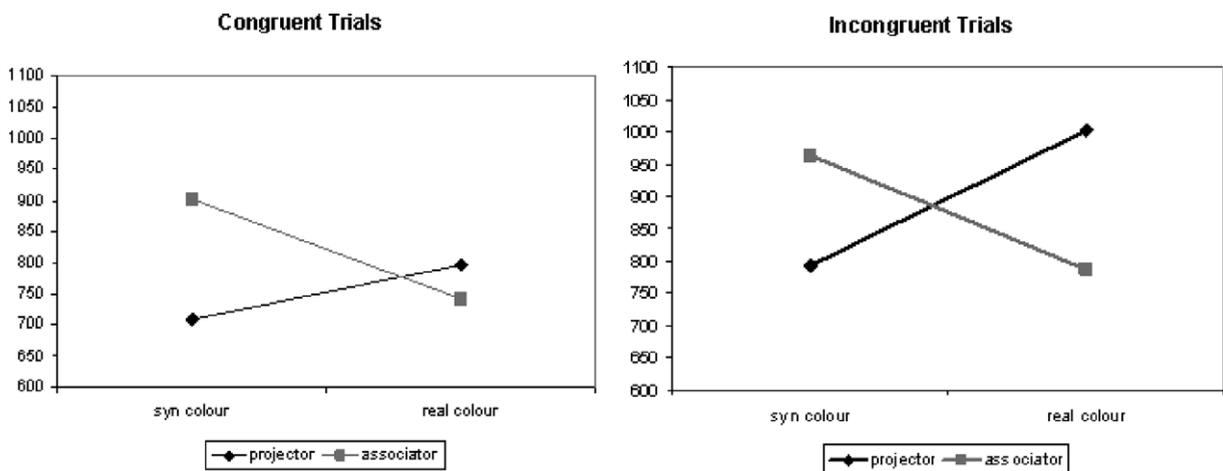

Fig. 1. Colour naming voice onset times (ms) for projector and associator synaesthetes in the tasks of naming their synaesthetic colour (ignoring real colour) versus naming the real colour (ignoring the synaesthetic colour).

interference in synaesthesia. There were no significant main effects of group ($F(1,12) = .09$, NS) or task-set ($F(1,12) = .43$, NS). This suggests that, overall, the two groups of synaesthetes had similar response times and that, overall, the tasks were of similar difficulty. However, the predicted interaction between group × task-set was found ($F(1,12) = 8.26$, $P < .05$). This reflects the fact that the projectors were faster than associators in naming the synaesthetic colours but the reverse was true for naming the veridical colour. No other interactions were significant, although the interaction between congruency and group approached significance ($F(1,12) = 3.40$, $P = .09$). The trend for projectors to name synaesthetic colours faster than real colours was observed in 5 out of 7 cases, and the trend for associators to name real colours faster than synaesthetic colours was also found in 6 out of 7 cases (Dixon et al. report the predicted pattern in 11 out of 12 synaesthetes that they tested). As such, this test provides a relatively reliable way of discriminating between projectors and associators at an individual level.

One novel aspect of the present study concerns the two cases (MKS and EP) who experience colours in external space but in whom the colours are not subjectively bound to the grapheme on the screen/page. Although we only had observations from two such participants, both synaesthetes were slower at naming their synaesthetic colours relative to real colours (268 and 168 ms difference between these conditions for MKS and EP, respectively, collapsing across congruency levels). As such, it is important to clarify that it is not the presence of externally perceived colours that determines behaviour as a projector but whether the colours are subjectively bound to a visually presented grapheme. We offer an account of this in Section 4.

3.2. Experiment 2: Crowding experiment

This experiment is based on that reported by Hubbard et al. (2005a). They found that some synaesthetes are better able than controls at detecting graphemes presented in the periphery. This ability correlated with the degree of activity in early cortical areas in an unrelated task (passively viewing graphemes relative to false font). The authors tested 6 synaesthetes in total and did not separate their participants according to the projector–associator dimension. However, there is some evidence to suggest that the important individual differences noted by Hubbard et al. (2005a, 2005b) may not map on to the projector–associator dichotomy. Three of their participants had previously been categorised as projectors in a number of other studies (e.g. Ramachandran & Hubbard, 2001a; Sagiv et al., 2006a). Two of these projectors (AD and JC) performed well, but one of them (CP) had the worst performance of the group. The present experiment sets out to explore whether performance on this task is indeed related to whether a synaesthete is a projector or not. If projectors are able to access synaesthetic colours without consciously recognising briefly presented graphemes then the prediction is that these synaesthetes should perform significantly better than associator synaesthetes.

3.2.1. Participants
The same set of 14 synaesthetes took part as in Experiment 1.

3.2.2. Methods
The method is identical to that used by Hubbard et al. (2005a, 2005b), although we reduced the number of trials. Four graphemes were chosen that elicited the synaesthetic colours of red, green, blue and yellow. Each of the graphemes served as a flanker versus central character an equal number of times utilising all possible permutations (i.e. 16). This basic set of 16 trials were repeated 8 times, 4 with the display appearing left of fixation and 4 with the display appearing right of fixation. The order of the 128 trials was randomised. Participants were seated 60 cm from the screen. Graphemes were presented in Arial font and subtended a visual angle of 1.2×1.6 degrees with centre-to-centre spacing of letters averaging 1.4 degrees. Each trial proceeded as follows. A central fixation cross appeared for 1000 ms, following which the display of 5 graphemes (a central grapheme surrounded by 4 flankers) was presented for 100 ms on either the left or right of fixation. This was followed by a pattern mask presented for 250 ms and then a prompt to type in which of the 4 digits had appeared in the centre of the configuration. There were no time constraints imposed on responding. The participant was instructed to fixate centrally at all times and the experimenter watched his/her eyes to try to ensure compliance with these instructions.

3.2.3. Results

The average percent correct for projectors was 57.0% (SD = 14.5, range = 37.5–78.9%) and for associators it was 46.7% (SD = 17.2, range = 30.5–76.6%). These did not differ from each other ($t(12) = 1.22$, NS). In summary, objective performance on this task does not reliably map on to the projector–associator distinction. There could well be some meaningful individual differences between synaesthetes as previously noted by Hubbard et al. but these do not necessarily map on to the projector–associator distinction. Previous studies of non-synaesthetes show a behavioural benefit in this task when graphemes are coloured (Kooi, Toet, Tripathy, & Levi, 1994). If projectors were able to induce synaesthetic colours pre-attentively then a behavioural benefit would be predicted for them, similar to that found for control participants when graphemes are coloured. Although the trend does go in this expected direction, subsequent replications (Experiment 3) show a trend in the reverse direction.

Although we failed to provide any behavioural evidence for a difference between projectors and associators, they reported different phenomenology during the task. At the end of the task, the synaesthetes were debriefed as to whether they experienced colours during the task. All 7 of the projector synaesthetes claimed to have had colour experiences during the task whereas only 1 associator claimed this. Whilst we cannot verify these claims, it does leave us with a paradox. If colours were experienced, why were not they helpful for identifying the grapheme? A number of options can be considered. Firstly, the flash of colour may have been too brief for them to commit to memory (or may have been over-ridden by the mask). Secondly, they may have experienced colours that were inappropriate (e.g. because the grapheme was partially recognised or mis-identified). Thirdly, it could be that colours were only experienced when also accompanied by conscious perception of a grapheme (as suggested by Mattingley et al., 2001). Thus, the colour would carry no added value in identifying the grapheme. Finally, it could be that they experienced colours but were unable to discern the colour of the central grapheme from that of the flankers. As such, the results of Experiment 2 are inconclusive. There are apparent phenomenological differences between projectors and associators on this task but it is not obvious how this affects behaviour, if at all. Experiment 3 was designed to clarify this issue.

3.3. Experiment 3: Crowding with non-graphemic distractors

The previous experiment found that projectors and associators did not differ, as groups, on their ability to detect a grapheme presented in the periphery and surrounded by distractor graphemes. However, the two groups did reliably report some phenomenological differences when debriefed. Namely, projectors reported experiencing colours during the task. Experiment 3 attempts to explore this finding by eliciting subjective reports, as well the behavioural measure, on a trial-by-trial basis. Specifically, participants will be asked after each trial whether they saw the grapheme, the colour, both or neither. Some studies have claimed that synaesthetes may be able to experience synaesthetic colours in the absence of grapheme perception whereas others claim that they do not. However, no previous study has compared groups of projectors and associators (demonstrating that a single projector shows the effect does not rule out the possibility that associators also show the effect, or that some projectors fail to show the effect). It is possible that the reason that projectors do not benefit from the additional presence of colour is that colour is only present on those trials in which the grapheme itself can be correctly identified. This would suggest an individual difference between projectors and associators, although the difference would not lie in whether colours are induced pre-attentively. Given the lack of a behavioural difference in the previous experiment, we also modified the nature of the distractors. It is possible that the null result in Experiment 2 arises because the projectors are unable to determine whether the perceived colour is elicited by the target or distractor grapheme. This was assessed by varying the graphemic status of the flanking distractors. In one test, the surrounding distractors were nonsense symbols. If there were competition between the colour of the target and the colour of the distractor then performance should be enhanced if the distractors do not elicit synaesthesia. This is compared to a separate condition in which one of the distractors is a grapheme and three of the other distractors are meaningless, and synaesthetically colourless, symbols. Examples of the stimuli used are shown in Fig. 2.

3.3.1. Participants

The same set of 14 synaesthetes took part as before. In addition, a set of 14 control participants were recruited to determine whether synaesthetes (as a group) show an advantage on the task. The
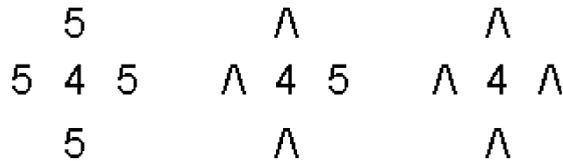
Fig. 2. An example of the stimuli used in Experiment 2 (left) and Experiment 3 (centre and right).

control participants consisted of 3 males and 11 females with an average age of 38.4 years (range = 20–67 years).

3.3.2. Methods

A similar method was used to that reported in Experiment 2 except in two key respects: the nature of the distractors were changed, and subjective reports were obtained on a trial-by-trial basis. The present experiment was divided into two blocks of 128 trials. In one block the centrally presented grapheme was surrounded by four meaningless symbols that did not induce synaesthesia. There were four different symbols used (e.g. /\, |¬, /}, \^). On a given trial, only one of these symbols was used. As such, the experiment was similar in design to Experiment 2 and also Hubbard et al. (2005a, 2005b). In the second block, the distractors were composed of three copies of the same meaningless symbol together with a distractor grapheme (one of the three non-presented graphemes). The distractor grapheme, meaningless symbol and target grapheme appeared equally often in all permutations except that we avoided situations in which the target grapheme and the distractor grapheme was identical (unlike in Experiment 2 and in Hubbard et al., 2005a, 2005b). The distractor grapheme appeared in each of the four possible flanker locations equally often. The procedure for each trial was the same as in Experiment 2, except that after choosing the grapheme the participant was asked about their phenomenological experience. They were given 4 options: (1) they saw a colour and saw the grapheme, (2) they saw the colour but not the grapheme, (3) they saw the grapheme but not the colour and (4) they saw neither (i.e. guessing). Experiment 2 suggested that projectors are more likely to report experiences of colour but this does not distinguish between options (1) and (2) above, which would suggest different theoretical explanations. The procedure for the controls was identical except for the omission of the phenomenological reports. Each control participant was closely age and sex matched to an individual synaesthete and was shown the set of four graphemes as were displayed to that synaesthete.

3.3.3. Results

In terms of behavioural differences, these were analysed as a $2 \times 2 \times 2$ ANOVA comparing group (synaesthete v. control), type of synaesthete/control (projector v. associator) and the nature of the distractors (4 nonsense flankers v. 1 graphemic flanker and 3 nonsense flankers). The results are summarised in Fig. 3. There was a significant main effect of type of distractor ($F(1,24) = 39.69$, $P < .001$) but no main effect of type of synaesthesia ($F(1,24) = .43$, NS) and no main group difference between synaesthetes and controls ($F(1,24) = .15$, NS). No interactions were significant or approached significance. If projectors were experiencing colours in a way that was similar to non-synaesthetes presented with truly coloured stimuli then we would expect them to perform better on this task, because the colour could be used to infer the identity of the grapheme. This would be expected to be particularly apparent in the condition in which only non-graphemic distractors are present.

Although these group results do not support our hypothesis that projectors outperform associators, a more interesting picture emerges when one contrasts behavioural performance with the phenomenological reports elicited on a trial-by-trial basis. As before, projectors are far more likely to report colour sensations than associators although they do not do so on each and every trial. Table 3 shows the proportion of trials in which synaesthetes reported perceiving a grapheme and/or colour. One of our projectors failed to report colours when performing the task, but all of the remaining 6 projectors reported colours with four of them reporting colours in the absence of overt recognition of a grapheme. Only 1 of the associator synaesthetes reported experiencing colours during the task, although this was always accompanied by reports of also perceiving the grapheme (and of high accuracy). As such, there is a high degree of inter-subject agreement within but not
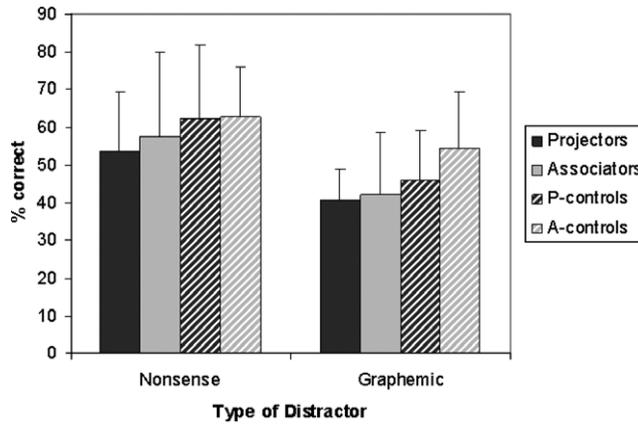
Fig. 3. The ability to identify a grapheme presented in the periphery (% correct, error bars show 1 SD) when surrounded by non-graphemic distractors or by a single grapheme and 3 non-graphemes.

Table 3
Percentage of trials in which synaesthetes report perceiving colours and/or graphemes (Experiment 3)

	Single grapheme flanker		Non-graphemic flankers	
	Projector	Associator	Projector	Associator
See colour, see grapheme	32.1	7.6	27.0	6.8
See colour, not grapheme	34.5	0.3	29.7	0.1
See grapheme, not colour	20.4	40.0	24.2	50.0
See neither (guessing)	12.9	52.1	19.1	43.1

across different types of synaesthete. A 2×2 ANOVA was performed, with the number of trials in which colours were reported (either with or without perception of a grapheme) as the dependent measure. The two independent variables were the type of synaesthete and the nature of distractors. The ANOVA confirmed that projectors are more likely to report colour experiences than associators ($F(1,12) = 15.63$, $P < .005$). There was also a significant main effect of the type of distractor ($F(1,12) = 5.92$, $P < .05$) suggesting that colours were more likely to be reported when one of the flankers was graphemic. The interaction was of borderline significance ($F(1,12) = 3.94$, $P = .07$).

Given that the phenomenological reports were obtained on a trial-by-trial basis, it is possible to back sort the trials according to whether reports of colour experiences are associated with greater accuracy, or whether more accurate trials are likely to be associated with reports of colour. This analysis is reported in Table 4 for the six projectors who reported colour experiences. Considering the condition in which all flankers were nonsense stimuli, trials in which the grapheme was correctly reported were more likely to also be associated with reports of colour experiences than trials in which the grapheme was incorrectly reported. However, the reverse

Table 4
Conditional probabilities that a colour is reported given a correct or incorrect target identification, and conditional probabilities that a correct target is chosen given the presence or absence of colour report

	Single grapheme flanker		Non-graphemic flankers	
	Probability (%)	Significance	Probability (%)	Significance
P (+colour | correct)	80.8	$t(5) = 1.36$, NS	74.8	$t(5) = 4.59$, $P < .01$
P (+colour | incorrect)	75.1		54.1	
P (correct | +colour)	44.9	$t(5) = 0.84$, NS	63.9	$t(5) = 1.30$, NS
P (correct | −colour)	40.6		56.6	

The data is taken from 6 projectors who report colour experiences during the crowding task.

does not hold true. Trials in which a colour is reported are not necessarily more accurate than trials in which no colour is reported. As such, behavioural performance is predictive of phenomenological reports but phenomenological reports do not significantly predict behaviour. The situation is less clear when one considers the condition in which a single grapheme was present amongst the flankers, as neither accuracy predicted colour reports nor did colour predict accuracy. However, it is to be noted that those trials in which a colour was reported even though an incorrect grapheme was chosen (i.e. P(+colour | incorrect) = 75.1%), are comprised of trials in which the incorrect response was to the flanker grapheme (P(+colour | flanker chosen) 80.2%) versus those in which one of the non-presented graphemes was chosen (P(+colour | non-presented grapheme chosen) 69.4%). If the latter figure is considered then there is a borderline significant result for a colour to be elicited on a correct trial relative to an incorrect trial in which the synaesthete selects a non-presented grapheme ($t(5)2.33$, $P = .068$; the trend is found in 5 out of 6 of the projectors considered). As such, on this second version of the task there is also some evidence of a relationship between accuracy of grapheme identification predicting the likelihood of colour perception (but not vice versa), as in the first task, although the results are partly obscured by the fact that the flanker also tends to elicit a colour and is often incorrectly chosen.

In summary, Experiment 3 has allowed us to clarify why reports of colour experiences cannot be used to boost accuracy in projectors as would be predicted if grapheme-appropriate colours were elicited even if the grapheme cannot be reported. Firstly, many of the colours are not appropriate to the grapheme that was actually presented (e.g. 54% of incorrect trials are noted to elicit a colour experience even when no grapheme is presented amongst the flankers). We can only speculate on why this might be. It is possible that features within the graphemes and flankers (i.e. oriented lines) either mis-combine or are sufficient in themselves to trigger a colour. However, this is odd given that false fonts and oriented lines do not elicit colour under free view conditions. In the crowding task, the synaesthetes are primed to expect to see one of four known graphemes and perhaps this is why partial visual information may trigger colour under these circumstances but not during free view. A second reason why colour experiences may not boost accuracy is that on many trials a colour experience may accompany accurate recognition of the grapheme but not necessarily precede it. Evidence for this comes from the fact that behavioural performance predicts the probability of reporting a colour but not vice versa (this result being more reliable on the meaningless flanker task). Finally, having a grapheme amongst the flankers is more likely to elicit a colour report, and projector synaesthetes find it hard to discriminate which grapheme is central or on the periphery of the configuration even when colours are noted. This suggests that colours are not pre-attentively bound to spatial locations in projector synaesthetes.

There is evidence that projector synaesthetes experience colours earlier than associators, but claims that these colours are appropriate for the grapheme (and hence can guide grapheme identification) or claims that graphemes and colours are bound together pre-attentively have been over-stated. Although the lack of difference in accuracy between projectors and associators is a null result (and therefore does not warrant strong claims), the significant relationship between accuracy of grapheme recognition and phenomenological reports of colour in projectors, but not associators, does provide an important source of constraint on models of grapheme-colour synaesthesia. Section 4 offers a new model of different varieties of grapheme-colour synaesthesia that links together the empirical evidence to date.

4. General discussion

The main finding that we wish to emphasise is that differences between grapheme-colour synaesthetes are real, insofar as different phenomenological reports can be associated with different behavioural profiles and that there is a high degree of inter-subject reliability between synaesthetes with the same profile. This contrasts with the alternative view that differences are variable over time (within individuals) and do not map on to differences in behaviour (between individuals, e.g. Edquist et al., 2006). We have observed that synaesthetes struggle to find the words to describe their experiences, and the same terms are often used to denote different things. For example, many synaesthetes restrict the use of the term "mind's eye" to denote internalised space, but others may use it to describe synaesthetic perception regardless of spatial location. This can undoubtedly lead to inconsistencies in categorising synaesthetes whose experiences are nonetheless stable.

It is also possible that differences in phenomenology extend beyond the projector–associator dichotomy. For example, our research suggests a distinction between projectors who experience colour on the surface

of a page (which we propose to call surface-projectors)[1] and those who experience colour in externalised near space (which we propose to call near space-projectors). On the task of Dixon et al. (2004), near space-projectors behave like associators. It remains to be determined if and how these two groups can be empirically discriminated. Moreover, it might be possible to empirically discriminate between associators who claim to see colours in some internal space (which we propose to call see-associators) and those who claim to know the colour of a grapheme (which we propose to call know-associators). This is in line with suggestions made by Block (2005) concerning dissociable mechanisms underlying phenomenal and access consciousness. Alternatively, perhaps these differences reflect individual differences in the way synaesthetes describe their experiences (e.g. some synaesthetes are more reluctant to over-extend the verb 'to see'). Moreover, none of these reported phenomenological differences map convincingly on to the higher–lower distinction although this distinction may nonetheless be useful and valid.

At this stage in synaesthesia research, what is needed is not an expanding list of differences but rather a coherent model in which differences may be explained. The model that we put forward to account for individual differences in grapheme-colour synaesthesia is summarised in Fig. 4. The core characteristics and assumptions of the model are listed as follows and will be described in detail in turn.

(1) There are different spatial frames of reference that exist in the brain. These may support normal imagery and perception as well as synaesthetic imagery and perception.
(2) The spatial reference frame that is evoked during synaesthesia differs from case to case (e.g. surface-projector v. associator), and from context to context (e.g. seeing v. hearing). The difference between projectors and associators primarily reflects differences in the spatial reference frame evoked during viewing text rather than differences in attentive v. pre-attentive processing or perceptual versus conceptual processing of the inducer.
(3) Attention operates over spatial frames of reference (as in non-synaesthetic perception) and all types of projector and associator synaesthetes require attentional mechanisms for accurate grapheme-colour binding. However, the attentional demands may not be identical in both types of synaesthesia (e.g. associators require dividing or shifting attention between different frames of reference).
(4) In principle, the distinction between higher and lower synaesthesia could reflect the degree of connectivity from the grapheme area to colour-responsive regions (lower synaesthesia) versus the degree of connectivity from conceptual representation to colour-responsive regions (higher synaesthesia). This is similar to what has been suggested before. In practice, the distinction is hard to pin down because: conceptual processing is automatic and inevitable, and there are no reported cases of synaesthetes who fail to show effects of context (e.g. given ambiguous stimuli).

With regards to the first aspect of the model (i.e. the existence of different spatial reference frames), this is well supported by evidence from neuropsychology and primate single cell recordings. For example, disorders of spatial attention such as hemi-spatial neglect reveals double dissociations between external space and imaginal or 'representational' space (Bartolomeo, 2002; Denis, Beschin, Logie, & Della Sala, 2002), between body-space and peri-personal space (Cocchini, Beschin, & Jehkonen, 2001; Guariglia & Antonucci, 1992), between near and far external space (Halligan & Marshall, 1991; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998) and between object-centred space and between-object space (Humphreys & Riddoch, 1994). The assumption that synaesthetic perception and imagery utilises the same spatial frames of reference as other forms of perception is less well grounded empirically. Our main motivation for assuming this is on the grounds of parsimony—namely that is desirable to explain as much as possible within a theoretical framework of normal cognition without needlessly postulating special mechanisms for synaesthetes. It does, however, lead to some interesting and novel insights as outlined below (e.g. concerning the projector/associator distinction). There is some empirical evidence from synaesthetes to suggest the importance of regions in posterior parietal cortex that are implicated in normal binding mechanisms (Esterman, Verstynen, Ivry, & Robertson, 2006) and

---

[1] An alternative term might be type-face projectors, but we have chosen to emphasise the space in which the colour is experienced rather than the object itself. Other surface-projectors might, for example, experience synaesthetic colours on the surface of faces rather than text.
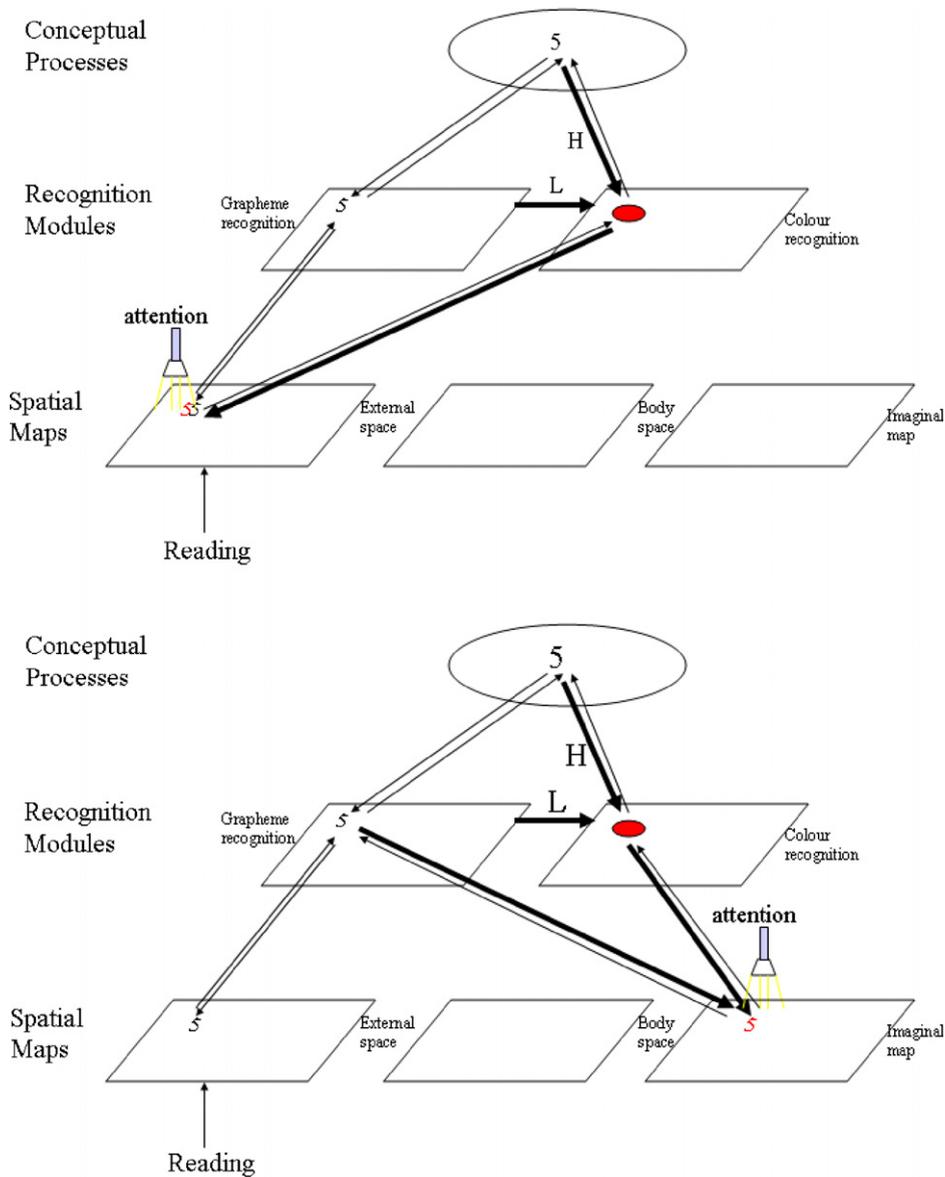
Fig. 4. A model of individual differences in grapheme-colour synaesthesia that takes into account different spatial frames of references (this explains many phenomenological differences) and different levels of induction (this may account for some features of the higher–lower distinction; H = higher, L = lower). The top and bottom models depict surface-projectors and see-associators respectively. The choice of spatial reference frames may depend on the task (e.g. reading v. thinking) as well as being idiosyncratic to a given synaesthete.

are frequently lesioned in cases of hemi-spatial neglect (Mort et al., 2003). A recent rTMS study disrupted syanesthetic Stroop interference when applied over right posterior parietal cortex (Esterman et al., 2006). This study was based on two surface-projector synaesthetes but another study has established that this region is important in associators (Muggleton, Tsakanikos, Walsh, & Ward, in press).

The notion of different spatial frames of reference goes a long way in explaining the phenomenology of synaesthetic experiences. Our assumption is that surface-projectors evoke an externalised frame of reference defined relative to the location of written words; near space-projectors evoke an externalised frame of reference defined relative to their body location (e.g. ''12 inch in front of me''); see-associators evoke an internalised frame of reference (e.g. that normally supports visual imagery); and know-associators perhaps do not

link their colours to any spatial reference frame or are the same category as see-associators. Some other associators also describe the location of their photisms as located within their body itself (e.g. "literally feels like in my head, a few centimetres behind my eye"), and these may evoke a body-based frame of reference. Future studies should attempt to directly manipulate the spatial reference frame that is attended in order to test this theory.

We explain the slowness in naming synaesthetic colours relative to real colours (Experiment 1) that is found in associators in terms of shifting attention from one spatial reference frame to another. In order to name their synaesthetic photism, they must attend to the grapheme located on the computer screen and then retrieve the corresponding colour from a different spatial location (their "mind's eye"). The same applies to near space-projectors who may also have to disengage attention from the grapheme location to the photism location. This is why these participants behave more like associators than surface-projectors on this task. For surface projectors, the synaesthetic photism is in the same location as the attended grapheme and this may enable more efficient naming of the synaesthetic colour relative to their associator counterparts. This leads to testable predictions. Associators should show neural correlates consistent with shifting between spatial locations/reference frames in photism naming but this should not be found in veridical naming or in the same tasks involving surface-projectors. Note that synaesthetic colours may be 'perceptually real' for both projectors and (at least some) associators. Hence, activation in regions such as V4 may be observed for associators too, although the colours may be perceived at different spatial locations. In the proposed model, the term 'perceptually real' becomes redundant because all types of synaesthesia involve aspects of perception, but they do so in different ways. The reason why surface-projectors are actually faster at naming synaesthetic colours relative to real colours is harder to explain—not just by the present model but also by all current models. Having the real and synaesthetic colour in the same location may lead to a competitive interaction in which the synaesthetic colour dominates over the real colour (e.g. the synaesthetic colour partially obscures or is more vivid than the real colour).

Other phenomena may also be accounted for in this framework. For example, it has been claimed that detecting a grapheme (Hubbard, Manohar, & Ramachandran, 2006) or judging the colour of a grapheme (Witthoft & Winawer, 2006) is affected by the background contrast (e.g. whether displayed on white or grey) in the two surface-projectors studied. This suggests that some synaesthetes are affected by contrast dependent stages of visual processing. This could be explained because both grapheme and background lie in the same spatial frame. The same may not be found for associators (although this remains to be shown) because their synaesthetic colour lies in a different spatial location to the external surface in which contrast is manipulated.

In this model, the defining feature of a surface-projector is the binding of colour to the location of an object in external space. However, we are agnostic about what this representation of external space consists of and where it may be located in the brain. Area V1 contains a representation of visual external space, but it is not the only region to do so. The activation of V1 could vary within a given group of projectors (e.g. as found in Hubbard et al., 2005a, 2005b), and could possibly be found in some near-space projectors (e.g. MKS who sees colours on a floating external screen). Perhaps some synaesthetes will show a dissociation between colours in near external space and far external space, as reported in the neuropsychology literature (Vuilleumier et al., 1998) and single cell recording literature (Iriki, Tanaka, & Iwamura, 1996).

The distinctions between different spatial reference frames are likely to extend beyond grapheme-colour synaesthesia and could possibly be applied to all types of synaesthesia. Thus, the case of taste-colour synaesthesia reported by Downey (1911) experienced colours inside his/her mouth (a body-based spatial reference frame) although other cases we have observed experience them in their internal "mind's eye". Similarly, with spatial number forms these can be experienced in coordinates in near space relative to ones body or on some other inner screen (Sagiv et al., 2006b). The present study suggests that the location of spatial forms are independent of the location of synaesthetic photisms induced by visual grapheme recognition. That is, the spatial reference frame that is evoked is both task-dependent (e.g. recognising visual graphemes versus conceptualising time) and idiosyncratic to a given individual. The projector SN, reported in this study, also experiences projected colours when watching someone speak. Coloured written words are seen as emanating from someone's mouth as they speak and the words drop away towards the lower right of the speaker's mouth. Of the other synaesthetes that we tested, all report colour to be on an internalised or external body-centred space when listening to speech. Finally, we have observed an equivalent of the projector–associator distinction in

individuals who experience taste from written and spoken words (lexical-gustatory synaesthesia).[2] Many of these individuals, including JIW whom we have studied at length (Ward & Simner, 2003; Ward et al., 2005), insist that their experiences of flavour are subjectively located in their mouth. For other synaesthetes that we have observed, the experiences are described as complex food associations but they are not subjectively felt in the mouth (these synaesthetes often describe it as a form of 'knowing' that does not have spatial location).

The explanation that we have put forward could be viewed as complicating rather than simplifying insofar as it leads to a proliferation of the number of varieties of synaesthesia beyond a projector–associator dichotomy. However, we feel that the model we have proposed has important advantages: it accounts for more subtle differences between grapheme-colour synaesthetes; it offers a way of expanding the theoretical framework to other types of synaesthesia (e.g. involving taste or number forms); and it is explicitly based on theories derived from the non-synaesthesia literature.

There appears to be a tendency in the literature to regard projector synaesthetes as providing an example of anomalous binding, whereas associator synaesthetes are assumed to experience unbound colours. However, at least from a phenomenological point of view, this is not strictly accurate. Most associators claim to see a coloured copy of the grapheme in their minds eye.[3] Thus, they do report that colours are bound to a grapheme but it is the spatial location of the grapheme that differs from surface-projectors. Both represent cases of grapheme-colour binding. This preamble leads on to the third claim made by our model, namely that all types of grapheme-colour synaesthesia require attention to enable accurate binding of graphemes with colours. Attention is assumed to operate over spatially coded reference frames as suggested by the non-synaesthetic literature (Treisman, 1988; Treisman & Gelade, 1980). However, the attentional demands may not be equivalent in all types of synaesthesia. For example, consider the task of naming synaesthetic photisms. As already mentioned, for an associator this task would involve identifying the grapheme in external space followed by shifting (or dividing) attention to a different spatial reference frame in order to produce the colour. In our second task, involving briefly presented crowded graphemes in the periphery, we would have expected surface-projectors to outperform associators if they were able to use pre-attentively induced colours to infer the identity of the grapheme. This was not found, even when the graphemes were crowded by flankers that did not induce synaesthesia. Nonetheless, surface-projectors (but not associators) do report colours when performing the task even if they claim to not have seen the grapheme. However, the colours are not necessarily appropriate to the grapheme that was actually shown and colours were more likely to be reported on trials in which graphemes were accurately seen than those in which they were not. As such, a reasonable interpretation of this data is that synaesthetic colour induction arises early in grapheme processing (at least in surface-projectors) but is not necessarily appropriate until such time as grapheme recognition is also accurate. This is similar to the notion of a cascade of activation proposed by Smilek et al. (2001). Like Smilek et al., we argue that synaesthetic colour induction may begin before processing of the inducer is complete. However, we claim that the actual colour elicited will not necessarily be appropriate unless grapheme recognition has progressed to such a stage as for the grapheme to be identifiable and, furthermore, that a unified percept of grapheme and colour bound to the same spatial location requires attentional mechanisms. If there are two graphemes presented in the periphery, then it is possible that several synaesthetic colours are induced but attention is needed to attribute them to the correct spatial location (i.e. target versus flanker). For associators, it is conceivable that colours are also induced early but that the colours are less likely to be noticed given that they are located elsewhere. An alternative scenario is that for these synaesthetes, synaesthetic colour induction occurs after conscious grapheme perception (e.g. Mattingley et al., 2001). At present, we cannot distinguish between these hypotheses although

---

[2] The distinction between lexical-gustatory synaesthetes who 'know' versus 'perceive' the flavour arose out of discussion with Dr. Julia Simner.

[3] In a sample of 31 grapheme-colour synaesthetes whom we have classified as associators, 61% claim to see a coloured copy of the grapheme in their "mind's eye", whereas only 6% claim to see blocks of colour that do not take the shape of the grapheme. The remaining 32% claim to have a strong sense of "knowing" the colour but claim not to "see" it. These participants are harder to classify/explain although their colours are often as precise as other synaesthetes. It is conceivable that these synaesthetes activate colour representations from graphemes but do not link them to any spatial frame of reference. It would be interesting to contrast these different types of associator experimentally.

we favour the hypothesis that attention is necessary for all types of synaesthesia but that different attentional demands arise from different spatial considerations.

The fourth aspect of the model concerns how we may account for differences between higher and lower synaesthetes. Most of the empirical demonstrations above refer specifically to the projector–associator distinction, so our comments on the higher–lower distinction remain more speculative. Stimuli such as numbers exist not only as units of visual recognition (i.e. digits) but also have a conceptual representation in terms of cardinality (denoting the size of a collection) and ordinality (denoting the position in a sequence). The higher–lower distinction highlights the importance of these conceptual aspects in synaesthesia and there is good reason why it does so. Recent prevalence studies have suggested that the most common types of synaesthesia are to ordered sequences, particularly for time units such as days and months eliciting colour (Simner et al., 2006). Spatial forms involving number, time and the alphabet are even more common and tend to co-occur with each other (Sagiv et al., 2006b). These may well involve circuits within the parietal lobe that represent aspects of number, space, and colour-form binding (Hubbard et al., 2005b). The specific aspect of the higher–lower distinction that we wish to dispute here is whether or not it maps on to the projector–associator distinction, and we argue that it does not. Experiencing spatial forms for numbers and time units does not closely map on to this distinction, and nor does the spatial location of the forms (i.e. whether the time line is perceived in external or internal space). Other evidence is consistent with this. Case studies of projectors have shown that magnitude judgments can be biased if the colour of the stimuli correspond to the colour of numbers (Cohen Kadosh & Henik, 2006; Cohen Kadosh et al., 2005). This suggests a close link between colour and the meaning of numbers in some projectors (i.e. they are unlikely to be 'lower'). Also, Stroop-like effects can be elicited from an arithmetic sum (e.g. 5+2) in which a quantity is implied (i.e. 7) but not seen, both in projector synaesthetes (Dixon, Smilek, Cudahy, & Merikle, 2000) and associator synaesthetes (Jansari, Spiller, & Redfern, 2006). This would not be expected if projectors were lower synaesthetes in whom colour was linked to the physical form of the digit rather than conceptual aspects of number.

Although conceptual properties of a stimulus may be important in synaesthesia, it is an open question whether 'higher synaesthesia' should be regarded as a discrete entity or whether it could be fractionated. For example, maybe some synaesthetes are 'higher' in the sense of possessing spatial forms (linked to ordinality) and other synaesthetes are 'higher' in the sense of showing priming of colours from a number concept (e.g. "5+2" primes the colour of 7). It is also possible that many synaesthetes have mixed 'higher' and 'lower' aspects. For example, Ramachandran and Hubbard have speculated that coloured spatial number forms reflect cross-activation between number areas (parietal) and secondary colour areas (temporo-parietal). However, an alternative scenario is that they reflect two events: cross-activation of number and space (parietal, 'higher') and cross-activation of digits and colour (fusiform, 'lower'). In the model outlined in Fig. 4, it is suggested that most cases of grapheme-colour synaesthesia may involve a mixture of conceptual and non-conceptual influences although the balance between them may differ from case to case. It is also likely that there are direct interconnections between numerical concepts (drawn at the top of our model) and spatial reference frames (drawn at the bottom of the model) that arise from their proximity within the parietal lobes (Hubbard et al., 2005b; Walsh, 2003).

In summary, we conclude that differences between grapheme-colour synaesthetes are real and important. We suggest that many of these differences arise from differences in the spatial reference frame utilised by the synaesthesia during a given task (e.g. viewing graphemes, hearing, tasting). This model could potentially be adapted to incorporate all other types of synaesthesia given that virtually all synaesthetic percepts have a strong spatial component.

Acknowledgment

References

Bartolomeo, P. (2002). The relationship between visual perception and visual mental imagery: A reappraisal of the neuropsychological evidence. *Cortex, 38*, 357–378.

Block, N. (2005). Two neural correlates of consciousness. *Trends in Cognitive Sciences, 9*, 46–52.

Cocchini, G., Beschin, N., & Jehkonen, M. (2001). The fluff test: A simple task to assess body representational neglect. *Neuropsychological Rehabilitation, 11*, 17–31.

Cohen Kadosh, R., & Henik, A. (2006). When a line is a number: Color yields magnitude information in a digit-color synaesthete. *Neuroscience, 137*, 3–5.

Cohen Kadosh, R., Sagiv, N., Linden, D. E. J., Robertson, L. C., Elinger, G., & Henik, A. (2005). Do colors influence numerical cognition in synaesthesia? *Journal of Cognitive Neuroscience, 17*, 1766–1773.

Denis, M., Beschin, N., Logie, R. H., & Della Sala, S. (2002). Visual perception and verbal descriptions as sources for generating mental representations: Evidence from representational neglect. *Cognitive Neuropsychology, 19*, 97–112.

Dixon, M. J., & Smilek, D. (2005). The importance of individual differences in grapheme-color synesthesia. *Neuron, 45*, 821–823.

Dixon, M. J., Smilek, D., Cudahy, C., & Merikle, P. M. (2000). Five plus two equals yellow. *Nature, 406*, 365.

Dixon, M. J., Smilek, D., & Merikle, P. M. (2004). Not all synaesthetes are created equal: Projector vs. associator synaesthetes. *Cognitive, Affective and Behavioral Neuroscience, 4*, 335–343.

Downey, J. E. (1911). A case of colored gustation. *American Journal of Psychology, 22*, 528–539.

Edquist, J., Rich, A. N., Brinkman, C., & Mattingley, J. B. (2006). Do synaesthetic colours act as unique features in visual search? *Cortex, 42*, 222–231.

Esterman, M., Verstynen, T., Ivry, R. B., & Robertson, L. C. (2006). Coming unbound: Disrupting automatic integration of synesthetic color and graphemes by TMS of the right parietal lobe. *Journal of Cognitive Neuroscience, 18*, 1570–1576.

Galton, F. (1880a). Visualised numerals. *Nature, 21*, 252–256.

Galton, F. (1880b). Visualised numerals. *Journal of the Anthropological Institute, 10*, 85–102.

Grossenbacher, P. G., & Lovelace, C. T. (2001). Mechanisms of synaesthesia: Cognitive and physiological constraints. *Trends in Cognitive Sciences, 5*, 36–41.

Guariglia, C., & Antonucci, G. (1992). Personal and extrapersonal space: A case of neglect dissociation. *Neuropsychologia, 30*, 1001–1009.

Halligan, P. W., & Marshall, J. C. (1991). Left neglect for near but not far space. *Nature, 350*, 498–500.

Hubbard, E. M., Arman, A. C., Ramachandran, V. S., & Boynton, G. M. (2005a). Individual differences among grapheme-colour synaesthetes: Brain-behavior correlations. *Neuron, 45*, 975–985.

Hubbard, E. M., Manohar, S., & Ramachandran, V. S. (2006). Contrast affects the strength of synesthetic colors. *Cortex, 42*, 184–194.

Hubbard, E. M., Piazza, M., Pinel, P., & Dehaene, S. (2005b). Interactions between numbers and space in parietal cortex. *Nature Reviews Neuroscience, 6*, 435–448.

Humphreys, G. W., & Riddoch, M. J. (1994). Attention to within-object and between-object spatial representations: Multiple sites for visual selection. *Cognitive Neuropsychology, 11*, 207–241.

Iriki, A., Tanaka, M., & Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurons. *NeuroReport, 7*, 2325–2330.

Jansari, A. S., Spiller, M. J., & Redfern, S. (2006). Number Synaesthesia: When hearing "four plus five" looks like gold. *Cortex, 42*, 253–258.

Kooi, F. L., Toet, A., Tripathy, S. P., & Levi, D. M. (1994). The effect of similarity and duration on spatial interaction in peripheral vision. *Spatial Vision, 8*, 255–279.

Laeng, B., Svartdal, F., & Oelmann, H. (2004). Does colour synesthesia pose a paradox for early-selection theories of attention? *Psychological Science, 15*, 277–281.

Mattingley, J. B., Rich, A. N., & Bradshaw, J. L. (2001). Unconscious priming eliminates automatic binding of colour and alphanumeric form in synaesthesia. *Nature, 410*, 580–582.

Mills, C. B., Boteler, E. H., & Oliver, G. K. (1999). Digit synaesthesia: A case study using a stroop-type test. *Cognitive Neuropsychology, 16*, 181–191.

Mort, D. J., Malhotra, P., Mannan, S. K., Rorden, C., Pambajian, A., Kennard, C., et al. (2003). The anatomy of visual neglect. *Brain, 126*, 1986–1997.

Muggleton, N., Tsakanikos, E., Walsh, V., & Ward, J. Disruption of the synaesthetic Stroop effect following right posterior parietal TMS. *Neuropsychologia*, in press.

Palmeri, T. J., Blake, R., Marois, R., Flanery, M. A., & Whetsell, W. (2002). The perceptual reality of synesthetic colors. *Proceedings of the National Academy of Science, USA, 99*, 4127–4131.

Ramachandran, V. S., & Hubbard, E. M. (2001a). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society of London B, 268*, 979–983.

Ramachandran, V. S., & Hubbard, E. M. (2001b). Synaesthesia—A window into perception, thought and language. *Journal of Consciousness Studies, 8*, 3–34.

Sagiv, N., Heer, J., & Robertson, L. (2006a). Does binding of synesthetic color to the evoking grapheme require attention? *Cortex, 42*, 232–242.

Sagiv, N., Simner, J., Collins, J., Butterworth, B., & Ward, J. (2006b). What is the relationship between synaesthesia and visuo-spatial number forms? *Cognition, 101*, 114–128.

Simner, J., Lanz, M., Jansari, A., Noonan, K., Glover, L., Oakley, D. A., et al. (2005). Non-random associations of graphemes to colours in synaesthetic and normal populations. *Cognitive Neuropsychology, 22*, 1069–1085.

Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S. A., Fraser, C., et al. (2006). Synaesthesia: The prevalence of atypical cross-modal experiences. *Perception, 35*, 1024–1033.

Smilek, D., & Dixon, M. J. (2002). Towards a synergistic understanding of synaesthesia: Combining current experimental findings with synaesthetes' subjective descriptions. *Psyhe, 8*.

Smilek, D., Dixon, M. J., Cudahy, C., & Merikle, P. M. (2001). Synaesthetic photisms influence visual perception. *Journal of Cognitive Neuroscience, 13*, 930–936.

Smilek, D., Dixon, M. J., & Merikle, P. M. (2003). Synaesthetic photisms guide attention. *Brain and Cognition, 53*, 364–367.

Treisman, A. (1988). Features and objects: The fourteenth Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology A, 40*, 201–237.

Treisman, A. (2004). Synesthesia: Implications for attention, binding, and consciousness—a commentary. In L. C. Robertson & N. Sagiv (Eds.), *Synesthesia: perspectives from cognitive neuroscience*. Oxford: Oxford University Press.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Vuilleumier, P., Valenza, N., Mayer, E., Reverdin, A., & Landis, T. (1998). Near and far visual space in unilateral neglect. *Annals of Neurology, 43*, 406–410.

Wagar, B. M., Dixon, M. J., Smilek, D., & Cudahy, C. (2002). Colored photisms prevent object-substitution masking in digit-color synesthesia. *Brain and Cognition, 48*, 606–611.

Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences, 7*, 483–488.

Ward, J., Butterworth, B., & Sagiv, N. Synaesthesia for finger counting and dice patterns: A case of higher synaesthesia? in preparation.

Ward, J., & Simner, J. (2003). Lexical-gustatory synaesthesia: Linguistic and conceptual factors. *Cognition, 89*, 237–261.

Ward, J., Simner, J., & Auyeung, V. (2005). A comparison of lexical-gustatory and grapheme-colour synaesthesia. *Cognitive Neuropsychology, 22*, 28–41.

Witthoft, N., & Winawer, J. (2006). Synesthetic colors determined by having colored refrigerator magnets in childhood. *Cortex, 42*, 175–183.