# DO SYNAESTHETIC COLOURS ACT AS UNIQUE FEATURES IN VISUAL SEARCH?

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## ABSTRACT

For individuals with grapheme-colour synaesthesia, letters, numbers and words elicit vivid and highly consistent colour experiences. A critical question in determining the mechanisms underlying the phenomenon is whether synaesthetic colours arise early in visual processing, prior to the allocation of focused attention, or at some later stage following explicit recognition of the inducing form. If the synaesthetic colour elicited by an achromatic target emerges early in visual processing, then the target should be relatively easy to find in an array of achromatic distractor items, provided the target and distractors elicit different synaesthetic colours. Here we present data from 14 grapheme-colour synaesthetes and 14 matched non-synaesthetic controls, each of whom performed a visual search task in which a target digit was distinguished from surrounding distractors either by its unique *synaesthetic* colour or by its unique *display* colour. Participants searched displays of 8, 16 or 24 items for a specific target. In the chromatic condition, target and distractor digits were presented in different colours (e.g., a yellow '2' amongst blue '5's). In the achromatic condition, all digits in the display were black, but targets elicited a different synaesthetic colour from that induced by the distractors. Both synaesthetes and controls showed the expected efficient (pop-out) search slopes when the target was defined by a unique display colour. In contrast, search slopes for both groups were equally inefficient when the target and distractors were achromatic, despite eliciting distinct colours for the synaesthetes under normal viewing conditions. These results indicate that, at least for the majority of individuals, synaesthetic colours do not arise early enough in visual processing to guide or attract focal attention. Our findings are consistent with the hypothesis that graphemic inducers must be selectively attended to elicit their synaesthetic colours.

Key words: synaesthesia, visual search, selective attention, subjective report, pop-out, serial search

## INTRODUCTION

Synaesthesia is a phenomenon in which particular sensory stimuli elicit unusual experiences either in a separate modality, or within the same modality (Rich and Mattingley, 2002). The most common form is grapheme-colour synaesthesia, in which letters and numbers elicit experiences of colour (e.g., Dixon et al., 2000; Mattingley et al., 2001). The colour induced by a letter or number is typically consistent over time, although the specific character-colour pairs often differ between synaesthetes (Baron-Cohen et al., 1993). There has been considerable recent debate regarding the perceptual processes required for an inducing character to elicit a synaesthetic experience. A central issue in this debate concerns the extent to which mechanisms of selective attention are required to link or 'bind' inducing characters with their synaesthetic colours to yield coherent, conscious experiences (Mattingley and Rich, 2004; Mattingley et al., 2001; Ramachandran and Hubbard, 2001a, 2001b; Rich and Mattingley, 2002, 2003; Robertson, 2003; Smilek et al., 2003). In the present study, we examined whether synaesthetic colours act as unique features during visual search, and thus whether they tend to guide focal attention to the location of a target in an array of otherwise similar distractors.

Several different approaches have been used to determine the role of attention and awareness in synaesthesia. Mattingley et al. (2001) used a priming task with 15 grapheme-colour synaesthetes, in which a letter prime induced a synaesthetic colour that was either congruent or incongruent with a subsequent coloured target. When the prime was visible, synaesthetes were slower to name the colour of the target on incongruent trials than on congruent trials. When the prime was masked from awareness, however, performance was unaffected by the relationship between the synaesthetic colour induced by the letter and the target colour. Mattingley et al. (2001) concluded that synaesthetic colours are only induced when synaesthetes are aware of the identity of the inducing stimuli.

In contrast, other authors have argued that synaesthetic colours can be elicited prior to recognition of an inducing stimulus (Ramachandran and Hubbard, 2001a; Smilek et al., 2001). Smilek et al. (2001) presented a synaesthete with brief, masked digits on a coloured background, and found that when the background matched the synaesthetic colour induced by the digit, she was significantly poorer in identifying the digit relative to trials in which the background and synaesthetic colour were different. Smilek et al. (2001) interpreted their findings as evidence that synaesthetic colours can be induced prior to awareness of digit identity.

There is considerable evidence that stimuli only reach awareness when they are selectively attended (Merikle and Joordens, 1997). Other studies have therefore focused explicitly on whether synaesthetic colours are induced prior to selective processing and can therefore guide attention. Visual search is a common behavioural task for investigating attentive and preattentive processing (Treisman and Gelade, 1980; Wolfe, 1998; Wolfe et al., 1989). Processing of basic features such as colour seems to occur in parallel across the visual field, without the need for selective attention (Treisman and Gelade, 1980). For example, search for items defined by a unique feature, such as looking for a red target among green distractors, is highly efficient and is hardly affected by the number of distractors. When search times are plotted as a function of the number of items in a display, the slope of this search function is relatively shallow. In contrast, targets that share several features with surrounding distractors do not tend to capture attention. For example, searching for an 'L' among 'T's requires attentive, item-by-item processing. This results in significant increases in search times with increasing distractor-set size (Wolfe et al., 1989), and therefore a relatively steep search slope (Treisman and Gormican, 1988; Wolfe, 1998).

The rationale behind visual search experiments in synaesthesia is that if synaesthetic experiences are elicited by inducers (e.g., digits) without focused attention, then a target that is distinct from the distractors by virtue of its unique synaesthetic colour should guide or capture attention; this should lead to highly efficient search, analogous to the effect of unique display colours. If, however, an inducer does not elicit a synaesthetic colour until it is attended, then search for an achromatic target digit among other achromatic digits should be relatively inefficient, resulting in a steep search slope.

Several recent studies have examined visual search performance in individuals with synaesthesia. Palmeri et al. (2002) presented a grapheme-colour synaesthete, WO, with a visual search array of achromatic digits. In one condition, the target digit induced a synaesthetic colour that was different from the colour evoked by the distractors. In a second condition, the target and the distractors induced the same synaesthetic colour. WO's search was more efficient (i.e., less influenced by increases in set size) when the target induced a unique synaesthetic colour, relative to the condition in which the target and distractors induced the same colour. This improved efficiency disappeared when the distractors were characters that did not induce synaesthesia. The authors suggested that as attention is deployed across a search array, the unique synaesthetic colour induced during recognition of an item might have allowed WO to reject distractors more quickly.

Laeng et al. (2004) replicated the Palmeri et al. (2002) study with another grapheme-colour synaesthete, PM. They also found that when the target differed in synaesthetic colour from the distractors, an otherwise difficult search became extremely efficient. However, further analysis revealed that PM's efficient search only occurred when the target was close to the initial focus of attention. Laeng et al. (2004) proposed that when the target is located close to the current focus of attention, partial information from feature processing activates the target representation, which in turn activates the synaesthetic colour. They suggest that this cascading pattern of activation increases target salience, thus narrowing the attentional spotlight to the target location and facilitating rapid identification. Interestingly, Laeng et al. (2004) also found that search times for targets defined by display colours were more efficient than those defined only by a synaesthetic colour, suggesting that synaesthetic colours are not as salient as real colours in such tasks.

In another recent visual search study, Sagiv et al. (2006, in this issue, p. 232) presented two synaesthetes with rotated 'T's as distractors, and upright or inverted 'L's as targets. They reasoned that if synaesthetic colours are induced prior to attentive processing, upright Ls should result in efficient search, whereas inverted Ls should not induce synaesthetic colours, leading to inefficient search. They found no evidence that synaesthesia facilitated search for upright targets, indicating that the synaesthetes had no additional advantage when the targets were synaesthetic inducers.

Finally, in a novel manipulation of the standard visual search task, Smilek et al. (2003) presented a synaesthete, J, with an array of black characters on a coloured background. The target was one of two digits that induced synaesthetic colours for J, whereas the distractor characters did not induce synaesthesia. The background to these displays was coloured uniformly to be either congruent or incongruent with the synaesthetic colour induced by the target (so that congruent targets should be more difficult to find). When J searched for a target on a congruent background, she was less efficient than when the background was incongruent with the synaesthetic colour of the target. Smilek et al. (2003) concluded that the target attracted attention to its position in the array when its colour was perceptually distinct from the background.

This brief review highlights some conflicting results from previous visual search studies in synaesthesia. Some findings suggest that targets defined by a unique synaesthetic colour may attract focal attention (Smilek et al., 2003), or increase the efficiency of distractor rejection (Palmeri et al., 2002), implying a relatively early locus of synaesthetic induction. Other results, however, suggest that synaesthetic colours do not arise early enough during perceptual processing to attract or guide attention (e.g., Laeng et al., 2004; Sagiv and Robertson, 2005; Robertson, 2003). These discrepancies might simply be due to different subcategories of grapheme-colour synaesthesia (Dixon et al., 2004; Ramachandran and Hubbard, 2001b; Smilek et al., 2001). Smilek et al. (2001; Dixon et al., 2004) have suggested that individuals who see their synaesthetic colours "out in space" (so-called *projectors*) are categorically different from those whose experiences occur "in the mind's eye" (*associators*). They suggest that for projectors, synaesthetic colours are elicited prior to conscious or attentive processing of the letter or digit (Smilek et al., 2001), and can therefore guide attention, whereas for associators, synaesthetic colours arise only after attentive processing of the inducing stimuli. To address the issue of subtypes of synaesthesia in our study, we administered a structured questionnaire to all participants to determine the extent to which their synaesthetic experiences fitted within the projector *versus* associator dichotomy[1]. We found widely varying subjective experiences among our 14 participants, with the only common factor being an experience of colour for digits and letters. We therefore present our analyses for the group as a whole, but present the data for each participant separately to illustrate the extent of the individual differences.

The principal aim of the present study was to examine whether synaesthetic colours can guide attention, by comparing visual search efficiency for targets defined by a unique synaesthetic colour with efficiency for targets defined by a unique display colour. We also investigated the effect of advance knowledge of target identity on visual search efficiency, to test the hypothesis that synaesthetes can use top-down strategies to help them reject distractors more rapidly than non-synaesthetes. If unique synaesthetic colours can guide attention in the same way as display colours, then synaesthetes should be as efficient when the digits are achromatic as they are when the digits are coloured. In contrast, non-synaesthetic controls should show the classic "serial search" patterns in the achromatic condition, with search time varying as a function of the number of distractors. If synaesthetes can use strategies to reduce the time needed to decide whether an item is a target or a distractor, then advance knowledge of target identity should increase the efficiency of search in synaesthetes relative to conditions in which target identity is unpredictable.

## METHOD

### *Participants*

Fourteen grapheme-colour synaesthetes (13 female; all right-handed; mean age = 36.9 years, SD = 14.8 years, range: 12 to 57 years) participated in the study. We also tested 14 non-synaesthetic controls, matched for age, sex and handedness (mean age = 37.3 years, SD = 14.6 years, range: 12 to 55 years). There was no significant difference between the ages of the two groups, $t(26) = -.06$, $p > .05$. The average consistency of synaesthetic experiences induced by digits and letters was 88% (SD = 8.2%) over a test-retest interval ranging from 3 months to 4 years (for further details on the consistency measure see Mattingley et al., 2001). By contrast, the average consistency for non-synaesthetic controls was 26% (SD = 15.3%) over a test-retest interval of 2-4 weeks. Synaesthetes were significantly more consistent than controls, $t(19.8) = 13.50$, $p < .001$ (corrected for inequality of variance). All participants gave informed consent prior to being tested, and all had normal or corrected-to-normal vision.

To determine the subjective nature of the synaesthetes' colour experiences, participants were initially asked to select one of three statements that best described how their colours appeared: "out there in space", "in my mind's eye" or "neither" (after http://www.arts.uwaterloo.ca/~src/survey.htm) (Dixon et al., 2004). Nine of the 14 participants had previously responded to this question some 12 months earlier, allowing us to check their consistency. We also administered a structured questionnaire to further characterise participants' synaesthetic colour experiences and colour imagery (Table I). The non-synaesthetic controls were asked the two imagery questions only.

### *Apparatus*

An IBM-compatible computer running Inquisit through Windows 98 was used for stimulus presentation and data recording. Stimuli were presented on a 17-inch Dell CRT monitor, with a vertical refresh rate of 75 Hz. Responses were recorded via a standard keyboard.

### *Stimuli*

'Digital-font' numerals were presented on a mid-grey background. Digital-font letters were used for one individual (Synaesthete 11) who did not have synaesthetic experiences for numbers. Three characters were selected for each synaesthete: two were designated as targets and one as a distractor. These were chosen so that each character elicited a distinctly different synaesthetic colour (Figure 1a). Synaesthetes selected an appropriate colour for each character using a computer-generated colour palette, and were asked to rate the match between the computer-generated colour and their synaesthetic colour on a five-point scale from 1 (not at all well-matched) to 5 (perfectly matched). Only colours with ratings of at least 4 were used. In the *achromatic search task*, both target and distractor characters were presented in black (Figure 1b). In

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[1] We thank an anonymous reviewer for raising this as an issue and prompting us to investigate the subjective colour experiences of our synaesthetes.

TABLE I

*Subjective reports of synaesthetic colour experiences.* A. *Responses to a standard question concerning the locus of synaesthetic colours (after Dixon et al., 2004). I – initial response; II – response after 1 year.* B. *Responses to items concerning synaesthetic colours from structured questionnaire. Participants responded on a five-point scale: 1 = strongly disagree (– –), 2 = disagree (–), 3 = neither agree nor disagree (blank), 4 = agree (+), 5 = strongly agree (++).* C. *Responses to items concerning imagined objects from structured questionnaire (ratings same as in B)*

| A. Synaesthete | 01 | | 02 | | 03 | | 04 | | 05 | | 06 | | 07 | 08 | 09 | | 10 | 11 | 12 | 13 | | 14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Testing occasion | I | II | I | II | I | II | I | II | I | II | I | II | I | I | I | II | I | I | I | I | II | I | II |
| The colour is out in space | * | | * | | | | | | | | | | | * | * | * | * | | | | | | * |
| The colour is in my mind's eye | | * | | * | * | * | * | * | | | * | * | * | | | | | * | | * | * | * | |
| Neither | | | | | | | | | * | * | | | | | | | | | * | | | | |

| B. Synaesthete | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| When I look at a letter or number I *see* a colour | – | | + | + | ++ | – | ++ | ++ | ++ | ++ | ++ | – – | – – | + |
| When I look at a letter or number I get a *feeling* of colour | + | + | ++ | | – – | | ++ | – | ++ | – – | | ++ | – | ++ |
| The colour has the *same shape* as the letter or number | + | | + | | ++ | – | ++ | ++ | + | + | | – – | – – | ++ |
| The colour is some *other* shape | – – | | – | – | – – | – | – – | – | + | + | – – | ++ | + | – – |
| The colour looks like it is on the page | – – | – | – | + | ++ | + | + | + | – | – – | | – | ++ | ++ |
| The colour is not on the page, but it is out there in space | – | – | – | – | – – | – | – – | – | + | ++ | ++ | | – | – – |
| The colour is in my mind's eye | + | + | ++ | + | – | + | ++ | ++ | ++ | – – | ++ | | ++ | ++ |
| When I imagine a letter or number the colour is the same as when I look at the letter or number on the page | – | + | ++ | ++ | ++ | + | ++ | ++ | + | ++ | ++ | – – | – | ++ |

| C. Synaesthete | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| When I imagine a familiar object (e.g., a banana) I see it out in space | – | | – | | – | – | – – | ++ | + | ++ | | + | – | + |
| When I imagine a familiar object (e.g., a banana) I see it in my mind's eye | + | + | ++ | + | + | + | ++ | ++ | ++ | – – | ++ | – | + | ++ |

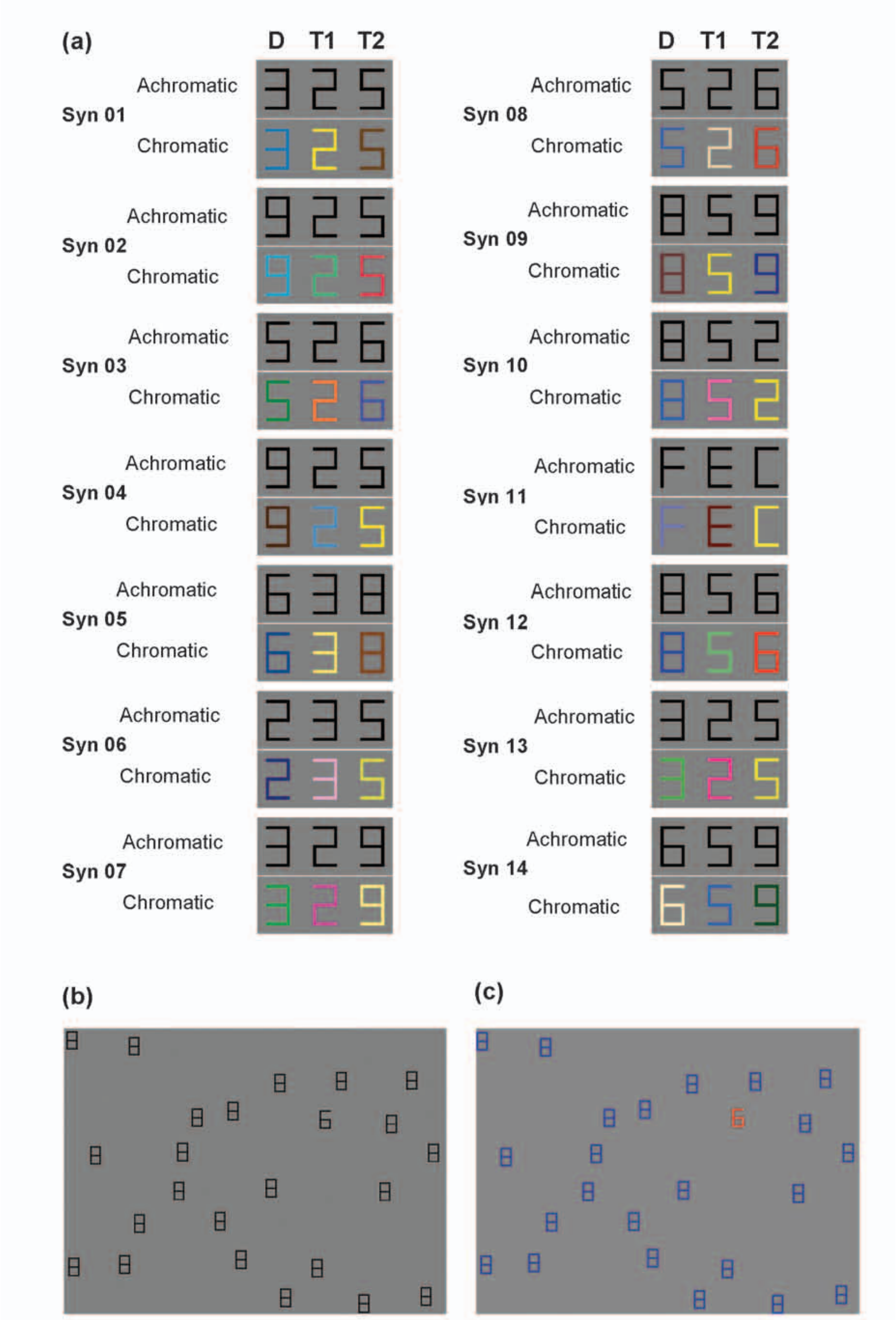

Fig. 1 – *Target and distractor stimuli used in the visual search tasks.* (a) *Individual stimulus items for each of the 14 synaesthetes: D = distractor; T1 and T2 = targets 1 and 2.* (b) *Example of an achromatic display for the largest set size (24 items).* (c) *Example of a chromatic display for the largest set size.*

the *chromatic search task*, each character was presented in the display colour that matched the individual synaesthete's experienced colour (Figure 1c). For each synaesthete, a non-synaesthetic control viewed identical stimuli.

At a viewing distance of 80 cm, the visual angle subtended by each character was 1.15° × .64°; the entire display subtended a horizontal visual angle of 11.65°. Characters were positioned using an algorithm that minimised clumping and ensured the visual angle subtended by the display was similar across the three different set sizes (8, 16 or 24 items).

### *Procedure*

Participants completed both the achromatic and chromatic search tasks in a single session, with the order counterbalanced within each group. In "target unknown" blocks, participants were instructed to search for either of two target digits, only one of which would appear on any given trial, and to indicate whether a target was present or absent using the left and right shift keys. The two targets appeared equally often within a block of 576 trials. In the "target known" condition, participants were informed of the target identity and then performed a block of 288 trials with one target digit, followed by a second block of 288 trials with the second target digit. Participants performed 24 practice trials for each condition before commencing the experimental task. Trials consisted of the presentation of a fixation cross for 500 msec, followed by the stimulus display, which remained on the screen until a response was made. No feedback on accuracy or response time was given. Targets replaced one of the distractor items on 50% of trials, appearing approximately the same number of times in each position. The number of items in the display (set size) was randomised within blocks. The order in which conditions were completed was counterbalanced across participants.

## RESULTS

We begin by considering the results from the questionnaire. As can be seen from Table IA, synaesthetes' responses to the question concerning how their colours appeared (Dixon et al., 2004) varied across the group. Six individuals indicated their colours appeared "in the mind's eye", three said their colours appeared "out in space" and two felt their experiences could not accurately be classified under either heading. Crucially, of the nine individuals who answered the question a second time after 12 months, only six gave the same response; three individuals changed from "out in space" to "in the mind's eye" or *vice versa*.

There was also considerable variability in the responses to our detailed questions about the nature of the synaesthetic experience (Table IB) and to the questions about the perceived locus of imagined, familiar objects (Table IC). Of particular interest were the participants' responses to the statements, "The colour looks like it is on the page" and "The colour is not on the page, but it is out there in space", compared with their responses to the statement "The colour is in my mind's eye". Of the 10 synaesthetes who endorsed either of the first two questions, indicating that their colours are perceived *externally*, eight also endorsed the third question, implying that their colours are experienced *internally*. Interestingly, five synaesthetes also claimed to experience visual images of familiar objects out in space, although three of these individuals also endorsed seeing such images in the mind's eye. To our knowledge this is the first systematic analysis of the subjective locus of synaesthetic colours and visual images. Though clearly preliminary, these findings suggest that the subjective experiences of synaesthetes are highly variable, and an individual synaesthete's description of this experience may change over time.

Given the findings from the questionnaire, rather than try and force individuals into arbitrary categories (e.g., projectors *vs.* associators) we analysed data from the visual search tasks for the group as a whole. However, the variability in subjective reports might also correlate with important, but as yet undefined, patterns of performance in visual search. For this reason we also present the results for each individual synaesthete and his or her matched control.

Participants completed two versions of the visual search task, one involving achromatic stimuli and the other involving chromatic stimuli. In separate blocks of trials the target was either specified (target known), or could be one of two different characters (target unknown). In the target known condition, mean accuracy across participants for target-present trials was 97% (SD = 3.2%, range: 85-100%), and for target-absent trials was 99% (SD = 1.3%, range: 95-100%). For the target unknown condition, mean accuracy across participants for target-present trials was 96% (SD = 3.7%, range: 81-100%), and for target-absent trials was 99% (SD = 1.12%, range: 95-100%).

Reaction times for correct, target-present trials were analysed statistically after removing outliers; these were defined as RTs less than 100 msec or greater than three standard deviations from the condition mean for each participant. Across conditions, outliers accounted for an average of 5% of trials (SD = 1.3%, range: 3-8%).

For each participant search slopes for target-present trials were calculated for each condition using linear regression. A three-way mixed ANOVA was performed on the mean slope value obtained from the individual linear regressions. The within-subjects factors were target condition (known, unknown) and display type (achromatic,

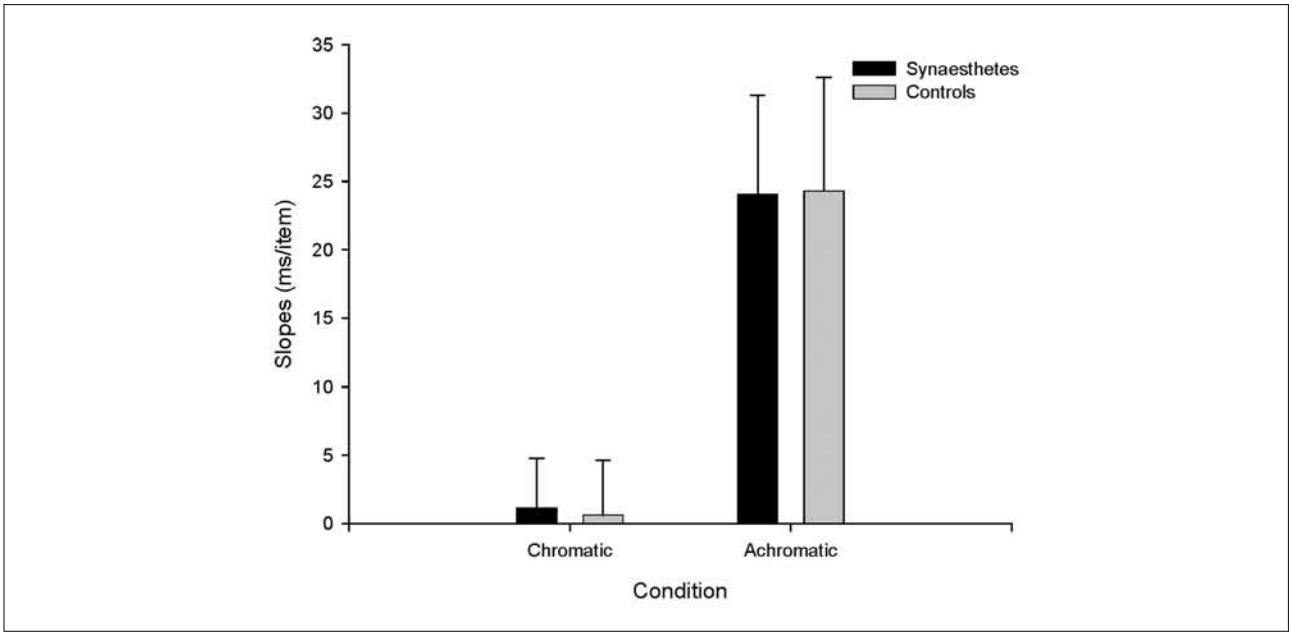

Fig. 2 – *Mean search slopes (+ 1 s.e.) for correct target-present trials, collapsed across target condition. Results for synaesthetes (black bars) and controls (grey bars) are plotted separately for achromatic and chromatic conditions.*

chromatic), and the between-subjects factor was group (synaesthetes, controls). There was a significant main effect of display type [F (1, 26) = 57.88, p < .001], but no significant main effect of target condition [F (1, 26) < 1, ns] or group [F (1, 26) < 1, n.s.] and no significant interactions [all two-way interactions F (1, 26) < 1; three-way interaction F (1, 26) = 2.22, p > .15].

Figure 2 shows the mean search slopes (in milliseconds per item) for the achromatic and chromatic displays, collapsed across target condition, for synaesthetes and controls. It is clear that the achromatic stimuli yielded a much steeper search slope than the chromatic stimuli, and this difference was nearly identical for the two groups. Similar patterns were evident for the target-absent data. For the achromatic displays, mean target-absent slopes were 59.7 msec/item (SD = 40.0) for synaesthetes and 59.8 msec/item (SD = 41.6) for controls. For chromatic displays, mean target-absent slopes were 3.2 msec/item (SD = 5.7) for synaesthetes and 2.7 msec/item (SD = 4.1) for controls.

Figure 3 shows the visual search performance for each individual synaesthete and his or her matched control, with separate functions for achromatic and chromatic displays. There is considerable variability in the search slopes across participants, some of which might be attributable to the different character sets present in each display. It is important to note, however, that we minimised any salient featural differences between characters by using a "digital" font (Figure 1). Each digit contained 3 horizontal-line segments and 2 to 4 vertical-line segments, thus maximising the shared features between targets and distractors. Moreover, the matched controls viewed identical stimuli to the synaesthetes, so any apparent differences between matched pairs cannot be due to differences in the search displays.

Inspection of Figure 3 does, however, reveal differences between some individual synaesthetes and their matched controls that are worthy of mention. For the critical achromatic condition, where one might predict an advantage for synaesthetes, individuals 5 and 11 both appear to have shallower search slopes than their matched controls. Note, however, that the control participant for Synaesthete 5 was also much less efficient than the other control participants. In fact, her mean search slope for target-present trials is > 2 SD above the control group mean. Moreover, the performances of both synaesthetic individuals were no more efficient than those of many other controls (e.g., see Pairs 1, 7, 9, 10, 12 in Figure 3). Finally, it is clear that at least two of the synaesthetes were actually less efficient than their controls in the critical achromatic condition (see Pairs 3 and 13, Figure 3). In summary, despite some individual variability the most compelling pattern to emerge is that synaesthetes and controls exhibit very similar search efficiency for both achromatic and chromatic displays, as confirmed statistically by our group analyses (Figure 2).

## DISCUSSION

The principal aim of this study was to investigate whether the synaesthetic colour induced by an achromatic digit can guide attention during visual search within an array of achromatic distractors. Both synaesthetes and non-synaesthetic controls showed highly efficient searches for

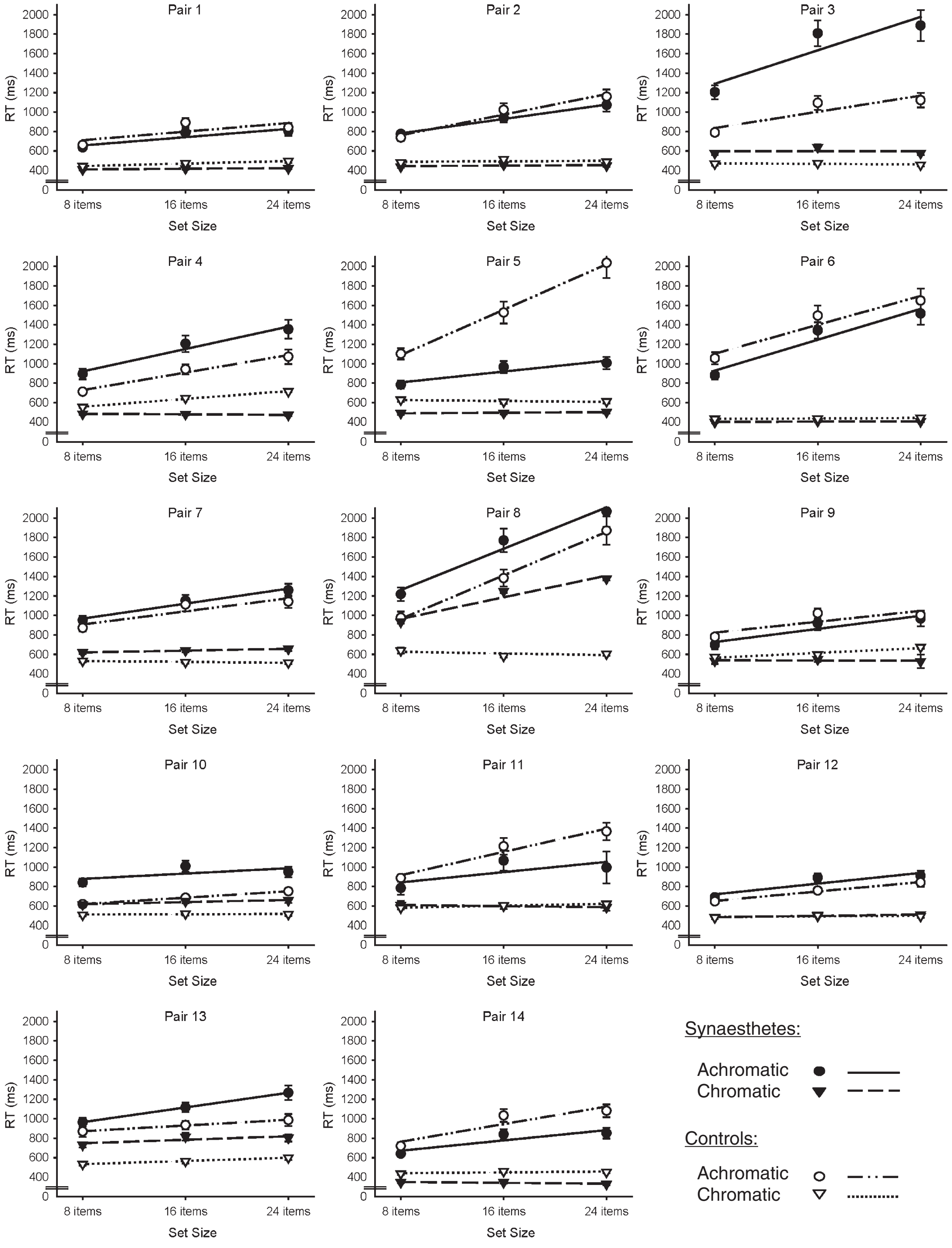

Fig. 3 – *Individual RTs for correct target-present trials (± 1 s.e.) as a function of set size, collapsed across target condition. Each graph (Pairs 1-14) shows the data for an individual synaesthete and his or her matched control. Different symbols show results for the achromatic and chromatic conditions. Solid and dotted lines are linear regressions, the slopes of which were used in the group statistical analyses.*

chromatic displays in which the target was defined by a display colour that differed from that of the distractors. In contrast, both groups showed relatively inefficient search for achromatic displays in which the target digit differed from the surrounding distractors in terms of its form only. Crucially, we found no compelling evidence for enhanced search efficiency in the group of synaesthetes, even though the target elicited a synaesthetic colour that was distinct from that of the distractor digits. The absence of a significant difference between the groups in either search task should be interpreted with some caution, given the interpretative difficulty of proving the null hypothesis. Nevertheless, as we discuss below, the existence of enhanced search efficiency for achromatic displays may be the exception rather than the rule in the case of grapheme-colour synaesthesia.

In light of recent suggestions that individuals with grapheme-colour synaesthesia can be divided into two distinct subtypes – projectors and associators – we probed each individual's subjective synaesthetic experience via a structured questionnaire. Somewhat unexpectedly, we found substantial variability in the responses of our participants. Some synaesthetes agreed that their colours occurred in the mind's eye, whereas others indicated that their colours appeared out in space. But two individuals felt their colours could not be described as occurring either internally or externally, despite experiencing their synaesthesia vividly and consistently. After an interval of a year, several individuals changed their description of where their colours appeared, even though the hues themselves were unchanged. Even more surprisingly, several synaesthetes considered that their colours occurred both in the mind's eye and out in space. To our knowledge this is the first detailed study of the subjective locus and consistency of synaesthetic colour experiences in a group of synaesthetes. Our simple questionnaire highlights the variability in subjective reports and raises the question of whether such measures alone can provide a reliable basis for theoretical distinctions between different subtypes of synaesthesia.

In the absence of a clear rationale for subdividing our synaesthetes into distinct subgroups, we performed group analyses on the visual search data, but also compared performance for each individual synaesthete with his or her matched control. Inspection of individual search slopes (Figure 3) revealed one or two possible differences in favour of synaesthetes, but none that would provide a compelling case for enhanced search efficiency. As stated earlier, we must be cautious in trying to prove the null hypothesis – indeed, there are two published cases that suggest such an advantage (Palmeri et al., 2002; Smilek et al., 2003) – but the present findings, from a relatively large group of grapheme-colour synaesthetes, indicate that any such effect is unlikely to hold for most individuals.

Taken together, the results of the present study suggest that for the majority of individuals, synaesthetic colours do not arise early enough in the visual processing hierarchy to guide or attract focal attention. This conclusion is consistent with that of Sagiv and Robertson (2005; Robertson, 2003), but seems to contradict the findings from two recent single-case investigations (Palmeri et al., 2002; Smilek et al., 2003). One possible explanation for this discrepancy is that the critical comparison in the Palmeri et al. (2002) study was between conditions in which the synaesthetic colours of target and distractor stimuli was systematically manipulated. These authors demonstrated that search time for a target that induced a different synaesthetic colour from the distractors was faster than search times for a target that induced a similar synaesthetic colour as the distractors. However, the recent findings of Laeng et al. (2004), who used an analogous task to Palmeri et al. (2002), suggest that the apparent synaesthetic benefit observed in the latter study might have been due to trials in which the target was located within the current attentional spotlight; such an account might also apply to the findings of Smilek et al. (2003).

The results of the current study are consistent with the proposal that for most grapheme-colour synaesthetes, induced colours arise only after attention is focused on the inducing stimulus. Further support for this idea comes from another study, in which we found that reducing the attentional resources available for processing an inducing letter significantly reduces synaesthetic interference in a Stroop-like task (Mattingley et al., 2006, in this issue, p. 213; see also Rich and Mattingley, 2003; Robertson, 2003). We conclude that in most cases synaesthetic colours are linked with their graphemic inducers following conscious recognition of the character, and that this process requires attention.

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