Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Cognition 98 (2005) 53–84
COGNITION
www.elsevier.com/locate/COGNIT

A systematic, large-scale study of synaesthesia: implications for the role of early experience in lexical-colour associations

A.N. Rich[a], J.L. Bradshaw[b], J.B. Mattingley[a,*]

[a]*Cognitive Neuroscience Laboratory, School of Behavioural Science, University of Melbourne, Melbourne, Vic. 3010, Australia*
[b]*Department of Psychology, Psychiatry and Psychological Medicine, Monash University, Vic. 3800, Australia*

Received 22 March 2004; revised 18 October 2004; accepted 11 November 2004

Abstract

For individuals with synaesthesia, stimuli in one sensory modality elicit anomalous experiences in another modality. For example, the sound of a particular piano note may be 'seen' as a unique colour, or the taste of a familiar food may be 'felt' as a distinct bodily sensation. We report a study of 192 adult synaesthetes, in which we administered a structured questionnaire to determine the relative frequency and characteristics of different types of synaesthetic experience. Our data suggest the prevalence of synaesthesia in the adult population is approximately 1 in 1150 females and 1 in 7150 males. The incidence of left-handedness in our sample was within the normal range, contrary to previous claims. We did, however, find that synaesthetes are more likely to be involved in artistic pursuits, consistent with anecdotal reports. We also examined responses from a subset of 150 synaesthetes for whom letters, digits and words induce colour experiences ('lexical-colour' synaesthesia). There was a striking consistency in the colours induced by certain letters and digits in these individuals. For example, 'R' elicited red for 36% of the sample, 'Y' elicited yellow for 45%, and 'D' elicited brown for 47%. Similar trends were apparent for a group of non-synaesthetic controls who were asked to associate colours with letters and digits. Based on these findings, we suggest that the development of lexical-colour synaesthesia in many cases incorporates early learning experiences common to all individuals. Moreover, many of our synaesthetes experienced colours only for days of the week, letters or digits, suggesting that inducers that are part of a conventional sequence (e.g. Monday, Tuesday, Wednesday…; A, B, C…; 1, 2, 3…) may be

* Corresponding author. Tel.: +61 3 8344 3976; fax: +61 3 9347 6618.
E-mail address: j.mattingley@psych.unimelb.edu.au (J.B. Mattingley).

doi:10.1016/j.cognition.2004.11.003

particularly important in the development of synaesthetic inducer-colour pairs. We speculate that the learning of such sequences during an early critical period determines the particular pattern of lexical-colour links, and that this pattern then generalises to other words.

Keywords: Colour perception; demographics; cognitive development; language; multimodal perception; synaethesia

1. Introduction

The phenomenon of *synaesthesia* has been described as a ‘mixing’ of the senses (Cytowic, 1989). For example, *hearing-colour* synaesthetes ‘see’ colours when they hear particular sounds (Baron-Cohen, Wyke, & Binnie, 1987), and *lexical-gustatory* synaesthetes experience particular tastes when they hear or read certain words (Ward & Simner, 2003). More commonly, however, the mixing of sensory experiences in synaesthesia occurs for different perceptual properties within the *same* modality; for instance, letters and digits may elicit synaesthetic experiences of colour (Rich & Mattingley, 2002). The synaesthetic colours may be induced by the visual appearance of a printed item, or by its sound when spoken aloud. Merely thinking about a particular letter, digit or word may also elicit a vivid colour experience (Dixon, Smilek, Cudahy, & Merikle, 2000).

Although accounts of synaesthesia in the scientific literature date from over 100 years ago (Galton, 1880), we know very little about the phenomenon or how it develops. Here we report a large-scale investigation of synaesthetic experiences in which we surveyed 192 self-reported synaesthetes. We present demographic and personal data, and document the relative frequency of different forms of synaesthesia. We then present detailed analyses on the responses of 150 synaesthetes who experience colours for letters, digits and words, and explore the relationship between the stimulus that elicits synaesthesia (the *inducer*) and the resulting experience (the *concurrent*; Grossenbacher & Lovelace, 2001).

Anecdotal reports have suggested that synaesthetes may possess a number of associated characteristics. Cytowic (1996) has noted that synaesthetes tend to be female, left-handed, often poor at mathematics and direction finding, and prone to ‘precognitive’ experiences such as predictive dreams and déjà vu. It has also been suggested that synaesthetes tend to be involved in creative or artistic pursuits (e.g. Galton, 1880; Ramachandran & Hubbard, 2001), and that synaesthesia runs in families (Galton, 1880). To our knowledge there has been only one formal study of the prevalence of synaesthesia and its associated characteristics (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996). Baron-Cohen and colleagues advertised in the *Cambridge Evening News* and the *Cambridge University Student Magazine* for individuals who thought they might have synaesthesia. Of the final sample of 26 people identified as synaesthetes, there was a gender bias of approximately 6 females to every male. The incidence of left-handedness in this group was comparable to that reported for the general adult population. Baron-Cohen et al. (1996) estimated the prevalence of synaesthesia as 1 in 2000 adults (0.05%), based on circulation figures for the two publications. By contrast, they found a higher prevalence (48.6%) among biological relatives of six of their synaesthetes, suggesting a probable familial link.

The consistency over time of synaesthetic concurrents elicited by specific inducers has been noted repeatedly (e.g. Dresslar, 1903; Galton, 1883; Ginsberg, 1923). Such consistency has increasingly become an essential precondition for classifying an individual as having synaesthesia (Cytowic, 1989), and stems mainly from an influential study of Baron-Cohen and colleagues (1987). They asked a synaesthete to record her synaesthetic colours for 103 words. When re-tested without warning 10 weeks later, she was 100% consistent in the colours she reported for the 103-item set. By contrast, a non-synaesthetic control was only able to recall 17% of the colour associations she provided for the 103 items after just two weeks, even though she had been instructed to try and remember them. Such tests of consistency have become the ‘gold standard’ for determining the ‘genuineness’ of synaesthesia (Baron-Cohen et al., 1996; Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Cytowic, 1989; 1997; Mattingley, Rich, Yelland, & Bradshaw, 2001; Rich & Mattingley, 2002; Ward & Simner, 2003), although we note that in some instances synaesthetic experiences can change over time (e.g. become weaker with age).

Despite the apparent consistency of synaesthetic experiences in most individuals, the concurrents induced by particular stimuli appear idiosyncratic in the sense that the same inducer will elicit a different concurrent for different people (e.g. Galton, 1880). For example, the letter ‘A’ might elicit dark red for one synaesthete, and lime green for another. It seems implausible that a genetic blueprint would specify the synaesthetic colour induced by each letter, given that letters and numbers are learned rather than innately specified (Marks & Odgaard, 2005). In fact, monozygotic twins in our sample report different colours induced by the same letters. It is more likely that learning is involved in the development of specific inducer-concurrent pairs. We might therefore expect common learning experiences in childhood to lead to some consistency *between* synaesthetes in the concurrents elicited by particular inducers. This hypothesis has never been tested prospectively in a large group of synaesthetes. Marks (1975) performed a meta-analysis on a substantial subset of the published literature on synaesthesia. He found that synaesthetic experiences for vowels, when divided into specific colour categories, could be mapped on to the colour dimensions of red–green, yellow–blue and white–black with high consistency. More recently, Day (2005) reported a considerable level of consistency in the colours induced by selected graphemes and phonemes, based on published and unpublished data. There is therefore some evidence that inducer-concurrent links in synaesthesia may not be completely idiosyncratic.

There is also evidence that early experiences can be critical in the development of synaesthetic inducer-concurrent pairs. Ward and Simner (2003) analysed the relationship between speech sounds and induced synaesthetic tastes in a lexical-gustatory synaesthete, JIW. They found that JIW’s synaesthetic tastes derived predominantly from foods he ate as a child, and that many of them were related phonologically or semantically to the name of the taste, so that, for example, the word ‘Virginia’ induced a taste of vinegar, and the word ‘bar’ tasted of milk chocolate.

In the present study, we employed a structured questionnaire to gather detailed information from 192 self-reported synaesthetes in Australia. We characterised the various types of synaesthesia in our sample, and examined the demographic and personal characteristics of the group (e.g. gender and handedness; occupation). Where possible, we compared synaesthete data with relevant population data. When such comparison data were not available, we used responses from a group of 50 non-synaesthetic controls. Because for most of the synaesthetes ($N=150$), letters, digits and words elicited colour experiences, we performed further analyses on the responses from this subgroup. We examined the consistency of colours over time for each synaesthete, and compared these results with those obtained from non-synaesthetic participants. We also determined whether there were any patterns of inducer-concurrent pairings over the group as a whole. Finally, we investigated possible sources of grapheme-colour associations by documenting the colours in which letters and numerals were printed in children's books published between 1862 and 1989. Our findings suggest that the relationship between the synaesthetic colour and an inducing item is influenced by whether the inducer is part of a conventional sequence (e.g. letters of the alphabet, days of the week), the age at which it was acquired, and the colour implied by its meaning. We speculate that the learning of sequences during an early critical period may determine the particular pattern of lexical-colour links, and that this pattern can then generalise to other words.

2. Method

2.1. Data collection

We collected data from synaesthetes throughout Australia between 1999 and 2003. The prevalence of synaesthesia was calculated based on the number of individuals who contacted the research group in response to an article on synaesthesia published in the magazine supplement of *The Australian* newspaper (*The Australian Magazine*; Dow, 1999). According to figures released by the publisher, the magazine had a national circulation of approximately 311,000.

A postal questionnaire was sent to all individuals who thought they may have synaesthesia. Items from the questionnaire are shown in Appendix A. We collected data on participants' demographic (age, gender, handedness, occupation) and personal (interests, medical and mental health history) characteristics, and on their particular experiences of synaesthesia. We asked about factors that influenced participants' synaesthetic experiences (e.g. attention, fatigue, drugs), perceived advantages or disadvantages of having synaesthesia, and factors relevant to the development of synaesthesia. Some questions were motivated by anecdotal reports of synaesthetes' characteristics (Cytowic, 1996), including open-ended items about cognitive strengths or weaknesses, and the type and frequency of any precognitive experiences (e.g. déjà vu). The second section of the questionnaire targeted individuals with synaesthetic experiences elicited by letters, digits and words (*lexical-colour* synaesthetes). Participants were asked to describe their synaesthetic experience for each of 150 items from eleven different categories: letters of the alphabet, digits, number words, days of the week, months of the year, and other nouns including animal names, place names, occupations, male and female names, and colour names. This section of the questionnaire was sent to participants again three months after they had completed the initial version, so that we could determine the consistency of synaesthetic experiences over time (Baron-Cohen et al., 1993, 1987).

We also collected personal and demographic data from a group of non-synaesthetes ($N=50$) who were matched for sex-, age- and handedness with a sub-sample of the synaesthetes. The non-synaesthetes were also asked to select a colour for each of the items in the questionnaire;[1] a measure of consistency was obtained by having these control participants complete the same task again after one month.

It is important to note that the synaesthetes were self-referred, and so in this sense they are not strictly a random sample from the general population. On the other hand, given the rarity of the condition it would be extremely impractical to obtain a truly random sample of nearly 200 synaesthetes. Moreover, there is no reason to suspect that our respondents reflect a particularly biased sample. *The Australian* newspaper has an approximately equal ratio of female and male readers, predominantly between 25 and 50 years of age, most of whom are professionals or white collar workers. Most of our analyses focus upon the 150 synaesthetes who reported colours for letters, digits and words. We demonstrate that the experiences of these synaesthetes are highly consistent over time, fulfilling the current 'gold standard' in the field (Baron-Cohen et al., 1996, 1993; Cytowic, 1989, 1997; Mattingley et al., 2001; Rich & Mattingley, 2002; Ward & Simner, 2003). We are therefore confident that our data from these synaesthetes provide an accurate snapshot of the underlying characteristics of the larger population of lexical-colour synaesthetes.

2.2. Exclusion criteria

We excluded individuals who experienced synaesthetic colours for alphanumeric symbols but who did not complete the second questionnaire ($N=22$), as we could not measure consistency for these individuals. This criterion did not apply if individuals had additional forms of synaesthesia, to avoid biasing the sample toward those with only lexical-colour synaesthesia. We excluded respondents under 16 years of age ($N=5$) due to ethical considerations, and individuals whose responses suggested other causes for their unusual experiences ($N=4$; e.g. dyslexia).

2.3. Response coding

We asked open-ended questions about demographic and personal details, medical history, and synaesthetic experiences (see Appendix A). The categories used in coding occupations and hobbies were not uniform, but were selected to allow detailed assessment of the hypothesis that synaesthetes would be more involved in artistic pursuits than non-synaesthetes. Thus, narrow categories were used for 'artistic' occupations (e.g. musician, photographer, architect), and broader categories were used for other occupations (e.g. administration/retail/marketing). Participants could be classified as having more than one occupation or hobby. Active involvement in a creative pursuit (e.g. playing music) was classified separately from a mere interest in an activity (e.g. listening to music). The nature of these categories and the coding for other analyses were guided both by the responses of synaesthetes and by previous anecdotal reports of synaesthesia (Cytowic, 1996; Galton, 1880; Ramachandran & Hubbard, 2001).

[1] For non-synaesthetes, colour names and a single female name were removed from the questionnaire for space reasons.

Lexical-colour synaesthetes ($N=150$) gave written descriptions, or used coloured pens or paints to respond to each item in the second section of the questionnaire. We classified responses according to the eleven basic colour categories (red, yellow, green, blue, purple, pink, orange, brown, black, grey, white; Berlin & Kay, 1969), with specific descriptors to indicate light–dark and bright–dull dimensions. For example, 'apricot' was coded as light orange, and 'silver' and 'gold' were classified as bright grey and bright yellow, respectively. Responses that could not be classified as a colour were excluded (e.g. clear or transparent); these represented less than 0.8% of responses. Where two separate colours were given (e.g. 'green and blue'), we coded the first-named colour as the primary hue (green), and the second as a secondary hue (blue). Where two colour names were combined (e.g. 'greeny-blue'), we defined the primary colour as that being modulated (blue), and the modifying colour as a secondary hue (green). In cases where more than two colours were given (e.g. 'red with greeny-blue flecks'), the dominant two colours were coded (red, blue).

For lexical-colour synaesthetes, initial questionnaire responses were compared with re-test questionnaire responses to assess the consistency of colour associations over time. Responses on the first questionnaire were used for all other colour analyses (e.g. consistency between individuals). We used a scale of 0–2 to assess consistency of the colour associated with each inducer. Responses were scored as completely consistent (2 points) if they were identical with respect to the primary colour and did not involve a secondary hue, or if they were identical for both the primary and secondary colours. Descriptions provided in the initial questionnaire were often more detailed than those given at re-test. Therefore, when the primary colour was identical at re-test but only one response included a secondary hue, a score of 2 was also given. Responses with only one of the colours (primary or secondary) consistent across questionnaires (e.g. 'blue/brown' versus 'blue/red') were scored as partially consistent (1 point). A consistency score of zero was given when neither the primary nor the secondary colours were the same at re-test.

3. Results

3.1. Types of synaesthesia, prevalence, and familiality

Less than 2% of the total sample reported synaesthetic experiences induced only by stimuli other than letters, digits, or words (Table 1). In contrast, 87% of the sample experienced synaesthesia for letters and digits (Tables 2A and B). The remaining 11% experienced synaesthesia from limited subsets of words but not from letters and digits (Table 3). Many synaesthetes reported that their colours appeared whenever they saw, heard, or thought about the letters, digits and words. Only one participant reported that the items had to be heard to induce a synaesthetic colour.

We estimated the prevalence of synaesthesia based on the national circulation of *The Australian* newspaper. We received 158 completed questionnaires, 86% of which were from women (6.1 females: 1 male). Consistent with previous reports (Baron-Cohen et al., 1996), this suggests that synaesthesia is far more common in

Table 1
Percentage of total sample ($N = 192$) with synaesthesia induced exclusively by non-lexical stimuli

N (%)	*Main inducers e.g. 'middle C'*	*Concurrent experiences e.g. 'red/earthy colour, smells like mud'*	*Second inducers e.g. 'scarlet'*	*Concurrent experiences e.g. 'high pitch ping'*	*Other inducers e.g. 'square'*	*Concurrent experiences e.g. 'tune follows angles of figure'*
1 (0.5)	Music	Colour Smell	Colours	Sounds	Shapes	Tune
1 (0.5)	Taste	Colour	–	–	–	–
1 (0.5)	Pain	Colour	–	–	–	–
3 (1.6)	Subtotal other stimuli					

Table 2A
Percentage of the total sample ($N = 192$) with synaesthesia induced by lexical stimuli. Synaesthesia for letters/digits only (with or without words)

N (%)	*Inducers e.g. 'A'*	*Concurrent experiences e.g. 'red'*
108 (56.3)	Letters/digits	Colour
2 (1.0)	Letters/digits	Colour Form[a]
1 (0.5)	Letters/digits	Colour Personality
1 (0.5)	Letters/digits	Colour Shape
1 (0.5)	Letters/digits	Form
113 (58.9)	Subtotal letter/digits	

[a] Spatial arrangement of items (e.g. "I see the alphabet arranged in a curved row, sequentially and coloured").

females than males.[2] We calculated the prevalence of synaesthesia in Australia separately for females and males. The estimated prevalence was 1 per 1150 (0.087%) for females and 1 per 7150 (0.014%) for males. This is likely to be a conservative estimate, as not every reader with synaesthesia will have contacted our research group.

The prevalence of synaesthesia among biological relatives was much higher than that estimated for the general population. Table 4 shows data from 69 participants (36%) who reported at least one biological relative with synaesthesia, presented separately for male and female respondents. Of the 61 female synaesthetes, 85% had at least one female relative with synaesthesia. Of the eight male synaesthetes, only two had male offspring with synaesthesia, and in neither case could we confirm father-to-son transmission.[3] Although 13% of the individuals in our sample did not know if they had any relatives with

[2] Although women may be more likely to respond to a media article, it seems unlikely that this alone accounts for the gender bias observed. The prevalence of male synaesthetes does seem to be higher among our familial cases, however, which could indicate that males are less likely to self-refer than females.

[3] Male-to-male transmission of synaesthesia requires a different mode of inheritance than the X-linked mode discussed by some investigators (Bailey & Johnson, 1997; Baron-Cohen et al., 1996).

Table 2B
Percentage of the total sample ($N=192$) with synaesthesia induced by lexical stimuli. Synaesthesia for letters/digits (with or without words) and other stimuli

N (%)	*Main inducers e.g. 'A'*	*Concurrent experiences e.g. 'red'*	*Second inducers e.g. 'C major scale'*	*Concurrent experiences e.g. 'yellow'*	*Other inducers e.g. 'headache pain'*	*Concurrent experiences e.g. 'blue, jagged'*
28 (14.6)	Letters/digits	Colour	Music/sound	Colour	–	–
3 (1.6)	Letters/digits	Colour	Music/sound	Colour Shape Movement	–	–
1 (0.5)	Letters/digits	Colour	Music/sound	Colour Shape Tactile quality	–	–
1 (0.5)	Letters/digits	Colour Gender	Music/sound	Colour	–	–
1 (0.5)	Letters/digits	Colour Texture	Music/sound	Colour	–	–
1 (0.5)	Letters/digits	Colour	Music/sound	Smell Taste Body sensations[a] Emotions	–	–
1 (0.5)	Letters/digits	Colour	Music/sound	Colour Shape	Pain	Colour Shape
1 (0.5)	Letters/digits	Colour	Music/sound	Colour	Emotions Body sensations	Colour
1 (0.5)	Letters/digits	Colour Personality	Music/sound	Colour	Emotions Body temperature	Colour
1 (0.5)	Letters/digits	Colour	Music/sound	Colour	Painting[b]	Music
2 (1.0)	Letters/digits	Colour	Music/sound	Colour	Smells	Colour
1 (0.5)	Letters/digits	Colour	Music/sound	Shape	Smells	Colour Texture
1 (0.5)	Letters/digits	Colour	Music/sound	Colour Shape	Tastes	Colour Shape
1 (0.5)	Letters/digits	Colour Personality	Music/sound	Colour Shape	Tastes Smells	Colour Shape Texture
1 (0.5)	Letters/digits	Colour Gender	Music/sound	Colour	Smells Faces	Colour
1 (0.5)	Letters/digits	Colour	Music/sound	Colour	Smells Time units Personalities	Colour
1 (0.5)	Letters/digits	Colour Gender	Music/sound	Colour Shape	Smells Body sensations	Colour Shape
1 (0.5)	Letters/digits	Colour Smell Taste	Music/sound	Smell Taste	Pain[c]	Sound
1 (0.5)	Letters/digits	Colour	Voices	Colour	Colours	Emotions

(continued on next page)

Table 2B (*continued*)

N (%)	*Main inducers e.g. 'A'*	*Concurrent experiences e.g. 'red'*	*Second inducers e.g. 'C major scale'*	*Concurrent experiences e.g. 'yellow'*	*Other inducers e.g. 'headache pain'*	*Concurrent experiences e.g. 'blue, jagged'*
1 (0.5)	Letters/digits	Colour	Voices[d]	Food quality	–	–
1 (0.5)	Letters/digits	Colour	Taste, smell	Colour	–	–
1 (0.5)	Letters/digits	Colour	Taste, smell	Colour sound Sound	–	–
1 (0.5)	Letters/digits	Colour	Pain	Colour Shape	–	–
1 (0.5)	Letters/digits	Colour	Personalities	Colour	–	–
54 (28.1)	Subtotal letters/digits plus other					

[a] e.g. "Bloat is red and yellow".
[b] e.g. "Kandinsky's geometric abstracts resonate with music–orchestral music coming and going".
[c] e.g. "The pain of PMT [premenstrual tension] sounds like bricks covered in cloth banging together".
[d] e.g. "There are people with 'custard' voices and people with 'toast' voices".

synaesthesia, more than half (51%) did not have any biological relatives with the condition.

3.2. Demographic characteristics of the sample

Table 5A shows demographic information for both synaesthetes and non-synaesthetes. We determined handedness by asking participants which hand they preferred to use for writing. Eight percent of female synaesthetes were left-handed, a value not significantly different from that found for adult females generally (5.9%; Oldfield, 1971), $\chi^2(1)=1.14$, $P>.1$. Eleven percent of male synaesthetes were left-handed, which also is not significantly different from that found for males generally (10.0%; Oldfield, 1971),

Table 3
Percentage of total sample ($N=192$) with synaesthetic colours induced by specific categories of words and other stimuli, but not by letters or digits

N (%)	*Main inducers 'Monday'*	*Concurrent experiences 'blue'*	*Second inducers 'lime'*	*Concurrent experiences 'green square'*
15 (7.8)	Words	Colour	–	–
1 (0.5)	Words	Colour	Music/sound	Colour
3 (1.6)	Words	Colour	Letters/numbers	Form
1 (0.5)	Words	Colour	Taste	Colour Shape
1 (0.5)	Words	Colour	Pain	Colour
1 (0.5)	Words	Colour Texture Sound Smell	Numbers/dates	Form
22 (11.4)	Subtotal words			

Table 4
Data from synaesthetes with biological relatives with synaesthesia, presented separately for male and female respondents, and for male and female relatives

Number of relatives with synaesthesia	*Gender of relatives with synaesthesia*	*Female participants N (%)*	*Male participants N (%)*
1	Female	31 (50.8)	4[a] (50.0)
	Male	8 (13.1)	1[b] (12.5)
2	Both female	4 (6.6)	2 (25.0)
	Both male	1 (1.6)	–
	1 female/1 male	5 (8.2)	–
	1 female/1 unspecified gender	2 (3.3)	–
3–4	All female	3 (4.9)	–
	Both female and male	4 (6.6)	1[c] (12.5)
>5	Both female and male	3 (4.9)	–
Total		61 (100)	8 (100)

Numbers in brackets indicate percentages of total number of participants, separated by gender, who have relatives with synaesthesia (females: $N=61$; males: $N=8$).

[a] This participant's wife had synaesthesia as well as his daughter.

[b] Possible case of male-to-male transmission of synaesthesia; alternatively, related males both with synaesthesia may have occurred by chance.

[c] This participant's wife had synaesthesia as well as his two sons, his daughter and brother.

$\chi^2(1)=0.4$, $P>.1$. Thus, there is no evidence that synaesthetes are more likely to be left-handed than non-synaesthetes.

Table 5B shows the occupations of both the synaesthetic and non-synaesthetic samples. Overall, 24% of synaesthetes were involved in artistic professions. In contrast, only one of the non-synaesthetes was involved in an artistic occupation, consistent with Australian census data indicating that less than 2% of the general population have artistic professions (Australian Bureau of Statistics, 2001). Table 5C shows the interests and hobbies of both groups.[4] There were no differences between the groups in the proportions actively involved in crafts ($\chi^2(1)=1.35$, $P>0.5$) or playing music ($\chi^2(1)=1.83$, $P>0.5$). However, more synaesthetes were actively involved in art (e.g. painting, drawing; $\chi^2(1)=149.16$, $P<0.001$) than non-synaesthetes. These data suggest that synaesthetes are more likely to be involved in artistic pursuits, consistent with previous anecdotal observations (Galton, 1880; Ramachandran & Hubbard, 2001).

As expected for our Australian sample, English was the native language of most individuals (94% of synaesthetes, and 88% of non-synaesthetes). Other native languages for individuals in the sample were Arabic, Chinese, Danish, Dutch, French, German, and Japanese. Fifty-nine percent of synaesthetes spoke at least one other language, and 28% of these were fluent in their additional language(s). Of the non-synaesthetes, 50% spoke at least one other language, and 48% of these were fluent in their other language(s). Significantly more synaesthetes than non-synaesthetes spoke another language

[4] Four synaesthetes and one non-synaesthete are classified as observers of art in Table 5C, as it was unclear if they were actively involved in art. The same is true for 15 synaesthetes and six non-synaesthetes regarding musical pursuits.

Table 5A
Demographic information for synaesthetes ($N=192$) and non-synaesthetes ($N=50$). Age, gender and handedness

		Synaesthetes	*Non-synaesthetes*
Age: (years)	Mean	49.3	39.8
	SD	16.2	13.4
	Range	16–86	17–63
Gender: N (%)	Females	165 (85.9)	45 (90.0)
	Males	27 (14.1)	5 (10.0)
	Total	192 (100.0)	50 (100.0)
Writing hand: N (%)	Right hand	176 (91.7)	44 (88.0)
	Left hand	16 (8.3)	6 (12.0)
	Total	192 (100.0)	50 (100.0)

($\chi^2(1)=6.41$, $P<0.05$), but synaesthetes were less likely to be fluent in this other language ($\chi^2(1)=16.56$, $P<0.001$). The degree of language fluency did not, however, seem to determine whether additional languages evoked synaesthesia: 88% of fluent speakers and 73% of non-fluent speakers reported synaesthesia from their additional language(s).

Table 5B
Demographic information for synaesthetes ($N=192$) and non-synaesthetes ($N=50$). Occupation

Occupation	*Synaesthetes Number of responses (%[a])*	*Non-synaesthetes Number of responses (%[a])*
Artist	11 (5.7)	–
Musician	3 (1.6)	–
Writer/journalist/photographer	15 (7.8)	1 (2.0)
Interior/fashion designer	2 (1.0)	–
Architect	1 (0.5)	–
Medical/allied health professional	20 (10.4)	4 (8.0)
Researcher/academic/scientist	8 (4.2)	7 (14.0)
Engineer	4 (2.1)	–
Lawyer	4 (2.1)	–
Teacher/lecturer—fine arts	4 (2.1)	–
Teacher/lecturer—music	4 (2.1)	–
Teacher/lecturer—dance	1 (0.5)	–
Teacher/lecturer—other/unspecified	29 (15.1)	4 (8.0)
Student—fine arts	3 (1.6)	–
Student—music	2 (1.0)	–
Student—other/unspecified	16 (8.3)	15 (30.0)
Information technology employee	8 (4.2)	2 (4.0)
Hospitality employee	2 (1.0)	1 (2.0)
Manager	11 (5.7)	6 (12.0)
Librarian	4 (2.1)	1 (2.0)
Administration/retail/marketing employee	32 (16.7)	11 (22.0)
Home/parent	15 (7.8)	1 (2.0)
Other	21 (10.4)	2 (4.0)

[a] Participants could nominate more than one occupation; percentages therefore do not add up to 100%.

Table 5C
Demographic information for synaesthetes ($N=192$) and non-synaesthetes ($N=42$). Interests/hobbies

Interests/hobbies	*Synaesthetes* *Number of responses (%[a])*	*Non-synaesthetes[b]* *Number of responses (%[a])*
Art (active)	58 (30.2)*	3 (7.1)
Crafts (active)	38 (19.8)	7 (16.7)
Music (active)	38 (19.8)	10 (23.8)
Art (interest)	14 (7.3)	2 (4.8)
Music (interest)	52 (27.1)	14 (33.3)
Photography	9 (4.7)	–
Writing/poetry	34 (17.7)*	3 (7.1)
Reading/literature	123 (64.1)*	20 (47.6)
Crosswords/languages	28 (14.6)*	3 (7.1)
Film/theatre/television	38 (19.8)**	13 (31.0)
Gardening/animals	75 (39.1)*	9 (21.4)
Sports/exercise	69 (35.9)	18 (42.9)
Outdoor activities/dancing	48 (25.0)**	17 (40.5)
Religion/spiritual pursuits	9 (4.7)	–
Meditation/relaxation	5 (2.6)	1 (2.4)
Work	3 (1.6)	–
Other	66 (34.4)	23 (54.8)

Analyses could not be conducted where zero cells exist. *Significantly more synaesthetes than non-synaesthetes, chi-squared analyses, $P<.05$. **Significantly less synaesthetes than non-synaesthetes, chi-squared analyses, $P<05$.

[a] Participants could nominate more than one interest; percentages therefore do not add up to 100%.

[b] Eight non-synaesthetes were not asked about interests.

Four individuals also reported experiencing synaesthesia from languages they did not understand. One synaesthete, KT, provided detailed notes about her synaesthesia for both her native language (English) and Modern Greek, which she learned as an adult (Table 6).

The medical history of most respondents was unremarkable. There were relatively few cases of major neurological illness or injury (16% of synaesthetes and 8% of non-synaesthetes). We specifically investigated the incidence of migraine, as the serotonergic system has been implicated both in migraine (Humphrey et al., 1990; Thomaides, Karagounakis, Spantideas, & Katelanis, 2003), and in the effects of psychedelic drugs such as mescaline, which can induce experiences similar to synaesthesia (Snyder, 1986). Neither female nor male synaesthetes were more likely to experience migraine than the general population (females: $\chi^2(1)=2.3$, $P>.1$; males: $\chi^2(1)=2.6$, $P>.1$; Rasmussen, 2001). Thirty-eight percent of synaesthetes reported a history of mental health difficulties, of varying frequency and severity. This is similar to population rates in the United States, where 48% of the population experience at least one episode of mental illness during their lifetime (Kessler et al., 1994).

Twenty-six percent of synaesthetes reported impaired vision and 7% reported impaired hearing. This included short- and long-sightedness corrected with glasses, and other such common problems. Although 60% of synaesthetes reported normal senses, 7% reported more acute vision than other people, 9% reported more acute hearing, and 10% reported

Table 6
KT's descriptions of her synaesthetic colours for Modern Greek and Roman alphabets at two time points, separated by 5 months

Letter	Name	Pronunciation	Comparison with Roman alphabet Time I	Comparison with Roman alphabet Time II
Α α	alpha	'a' as in 'father'	Daffodil yellow, same as 'a'	Yellow, same as 'a'
Β β	veta	'v'	Medium brown, same as 'b', not grey like 'v'	Brown, same as 'b'
Γ γ	gamma	like soft 'g'	Red, same as 'g'	Dull yellow, like 'y'*
Δ δ	delta	voiced 'th' as in 'that'	Dark brown, same as 'd'	Dark brown
Ε έ	epsilon	'e' as in 'tell'	Dark blue, same as 'e'	Dark blue, same as 'e'
Ζ ζ	zeta	'z'	Grey, same as 'z'	Same as 'z'
Η ή	eta	'ee' as in 'feet'	Dark green, same as 'n', not blue as 'ee' would be	Darkish green, same as 'n'
Θ θ	theta	unvoiced 'th' as in 'thimble'	Light brown (could be a mixing of the medium brown for 't' and buff for 'h')	Medium to light brown
Ι ι	iota	'ee' as in 'feet'	White, same as 'i'	White, same as 'i'
Κ κ	kappa	'k'	Very light blue as in 'k'	Pale blue, same as 'k'
Λ λ	lambda	'l'	Creamy white same as 'l'	White same as 'l'
Μ μ	mee	'm'	Medium green same as 'm'	Green same as 'm'c
Ν ν	nee	'n'	Light grey, same as 'v', not dark green like 'n'	Grey, same as 'v'
Ξ ξ	xee	'ks' as in 'box'	Medium grey, same as 'x'	Grey, same as 'x'
Ο ο	omicron	'o' as in 'hot'	Translucent, maybe slightly red, same as 'o'	Transparent, can give a red tinge to some surrounding letters
Π π	pee	'p'	Yellowy beige, not like 'p' which is pink	Light brown
Ρ ρ	rho	'r'	Pink, same as 'p', rather than red like 'r'	Pink, same as 'p'
Σ σ	sigma	's'	Blue, except for the final form, ς, which is pink like 'c'	Blue, same as 's'
Τ τ	tauf	't'	Medium brown, same as 't'	Dull brown, same as 't'
Υ υ	ipsilon	'ee' as in 'feet'	Buff, same as 'u'	Dull beige-yellow, same as 'u'
Φ φ	fee	'f'	Slightly darker buff than 'u'. It is the same as 'f' even though the shape is so different	Dull beige-light brown

(*continued on next page*)

Table 6 (*continued*)

Letter	Name	Pronunciation	Comparison with Roman alphabet Time I	Comparison with Roman alphabet Time II
Χ χ	chee	Like the 'ch' in 'loch'	Grey, like 'x', though a lighter grey than 'x'. (But I am sometimes overwhelmed by the pinkness of the 'c' in 'ch' and it seems pink)	Grey
Ψ ψ	psee	'psee'	Pink, same as 'p'	Pink
Ω ω	omega	'o' as in 'hot'	Light green same as 'w', not translucent/red like 'o'	Light bright green, same as 'w'

Lowercase Greek letters similar in shape to Roman letters induce the same synaesthetic colours, even if the Greek letters are pronounced differently. For example, 'β' is pronounced 'V', but induces brown like 'B' rather than grey like 'V'. The colours induced by Greek letters that do not resemble Roman letters are determined by pronunciation. For example, the letter ψ, pronounced 'psee', induces pink, the same colour as the letter 'P' in the Roman alphabet. *The only item to change between Time I and Time II. Notice the colour of the lower-case Greek letter changes from being determined by the sound to being determined by the form.

more acute smell and taste. This type of response was uncommon among non-synaesthetes: only 4% reported more acute vision. Empirical tests of basic threshold and discrimination sensitivity will be required to determine whether objective differences in sensory acuity exist between synaesthetes and non-synaesthetes.

3.3. Synaesthetic characteristics of the sample

Ninety-six percent of our synaesthetes reported having had synaesthesia for as long as they could remember, but many did not realise their experiences were unusual until adulthood. For example, SL, a 45 year-old woman, reported *"I became aware only about 5 years ago (from a magazine article) that seeing letters and numbers in colour was not normal"*. Other synaesthetes discovered they were unusual early in life, but negative reactions from others led them to keep their synaesthesia secret. Some participants clearly remembered having synaesthesia prior to attending school. For example, MT reported: *"I first experienced this at about age 2. My sister, who is 3 years older than I, had started school and I remember lying in our entrance hall wanting my 'BLUE' sister to come home."* Others first became aware of their synaesthesia when they were learning the alphabet, counting or reading. However, only 5% of synaesthetes believed their synaesthetic experiences resulted from early exposure to stimuli such as coloured letters; most (79%) could not describe the source of their synaesthetic experiences. Another 6% specifically reported having different letter-colour pairs to those they had seen early in life. For example, AM reported that as a child she played with *"a green M (which was right), but also a yellow M"*, and she was puzzled as to why an M would be made in the wrong colour. There were only seven respondents (3%) who did not recall having experienced synaesthesia in early childhood, and three of these recalled their first synaesthetic experiences from adolescence.

Eighty-nine percent of synaesthetes believed their synaesthesia was consistently linked to specific stimuli. This is consistent with objective measurements of consistency for lexical-colour synaesthetes, as we report below. Interestingly, 6% of respondents believed that their synaesthetic experiences were not consistent over time. Although some synaesthetes reported that the frequency or intensity of their synaesthetic experiences had diminished with age, most reported no change in their synaesthesia since childhood. Most individuals in the sample (88%) experienced synaesthesia on a daily basis. For example, RP reported that her synaesthesia occurs *"every time I say something, hear something, or read something. Even when I think."* Only 7% reported that synaesthesia did not occur regularly.

Seventy-six percent of the sample reported that their synaesthesia was not under voluntary control. Only 15% reported complete voluntary control over their synaesthesia, but a further 4% reported being able to induce synaesthetic experiences but not to prevent them. Despite the apparent absence of voluntary control of synaesthetic experiences for most individuals, 46% of respondents reported that focusing their attention could increase the vividness of their synaesthetic experience. In contrast, just 2% of individuals reported that attention decreased their synaesthesia. KP reported: *"It's kind of like looking at your own nose—if you try, you can see it clearly, but you don't walk around the whole time 'seeing' your nose. But it's always there and you can see it, just that you don't unless you're attending to it".* A further 46% of respondents believed that attention had no influence on their synaesthesia. These data suggest that for many synaesthetes, attention (or at least, self-monitoring) has a strong influence on the intensity of synaesthetic experience, consistent with findings from recent empirical studies (Mattingley, Payne, & Rich, in press; Rich & Mattingley, 2003; Sagiv & Robertson, 2005). Fatigue, emotional state or level of stress, and alcohol or other drugs modulated synaesthesia in 28% of respondents, either by attenuating or enhancing the experience.

Seventy-one percent of the sample (136 synaesthetes) reported that synaesthesia was advantageous, particularly for remembering information such as car registrations and telephone numbers. Some participants used their synaesthesia to organise files (e.g. matching the colour of a folder or label to a topic), and many reported that their synaesthesia was pleasurable and a source of creativity. A smaller proportion of the sample reported that their synaesthetic colours assisted in mathematics, particularly mental arithmetic, and in learning languages. RP wrote: *"I see words in foreign languages in colour too which makes learning a language easier—for example if I know the word for 'wonderful' in French is yellow, that immediately eliminates most words and makes remembering the appropriate word easier."* By contrast, 30% of the sample (58 participants) reported that synaesthesia could be a disadvantage. Of these, 35% confused words that elicited similar synaesthetic colours, and 10% reported conflict when a word's meaning was somehow inconsistent with its synaesthetic colour. For example, for KM the word 'starboard' is red. When she is sailing, she gets confused because red lights indicate 'port' and green lights indicate 'starboard'. Sixteen percent of participants reported that their synaesthesia interferes with tasks involving memory and mathematics. For example, MR wrote: *"I'm lousy at maths because you can't divide or multiply colours!"* Other participants (19%) experienced specific emotions as part of their synaesthesia, such as feeling negatively disposed toward people with names that elicited unpleasant colours, or being irritated by road signs that appeared in the ‘wrong’ colour. Nine percent of the 58 participants reported that synaesthesia overloads their senses and is exhausting in certain situations, and 7% found it uncomfortable to be ‘different’ from other people.

We also asked participants about their cognitive skills and weaknesses. We categorised responses according to certain characteristics that have been claimed to be associated with synaesthesia (e.g. Cytowic, 1996; Ramachandran & Hubbard, 2001), or that might be of generic interest (e.g. skills in learning languages). As shown in Table 7, of those who reported particular skills, significantly more synaesthetes than non-synaesthetes believed they had strengths in the areas of verbal and written communication, languages, and memory. Conversely, more synaesthetes than non-synaesthetes reported poor eye-hand coordination or balance, a poor sense of direction, difficulty with map reading, and problems distinguishing left from right. Although art and mathematics were mentioned in both categories, many more synaesthetes reported art as a strength, and mathematics as a weakness, than *vice versa*. Twenty-eight percent of synaesthetes and 18% of non-synaesthetes reported strengths other than those shown in Table 7, including speed-reading, proof-reading, planning and organisation, and social skills. Twenty percent of synaesthetes, and 3% of non-synaesthetes, reported weaknesses other than those included in Table 7, including technical or mechanical skills, planning and organisation, and social skills.

Table 7
Cognitive strengths and weaknesses reported by synaesthetes ($N=192$) and non-synaesthetes ($N=42$)[b]

Area	Strengths		Weaknesses	
	Synaesthetes Number of responses (%[a])	*Non-synaesthetes* Number of responses (%[a])	*Synaesthetes* Number of responses (%[a])	*Non-synaesthetes* Number of responses (%[a])
None	43 (22.4)	22 (52.4)	80 (41.7)	23 (54.8)
Visuospatial/visual	13 (6.8)	2 (4.8)	7 (3.6)	1 (2.4)
Verbal/communication	19 (9.9)*	1 (2.4)	–	–
Coordination/balance/sports	8 (4.2)	1 (2.4)	25 (13.0)*	3 (7.1)
Writing	31 (16.2)*	1 (2.4)	–	–
Spelling	9 (4.7)	–	4 (2.1)	–
Languages	21 (10.9)*	3 (7.1)	–	–
Crafts	10 (5.2)	2 (4.8)	6 (3.1)	1 (2.4)
Art	41 (21.4)*	2 (4.8)	5 (2.6)	–
Music	17 (8.9)	4 (9.5)	4 (2.1)	1 (2.4)
Memory	33 (17.2)*	2 (4.8)	6 (3.1)	1 (2.4)
Mathematics	9 (4.7)*	1 (2.4)	37 (19.3)	–
Sense of direction	6 (3.1)	–	28 (14.6)*	2 (4.8)
Map reading	6 (3.1)	–	5 (2.6)	1 (2.4)
L/R	1 (0.5)	–	8 (4.2)	–

Analyses could not be conducted where zero cells exist. *Significantly more synaesthetes than non-synaesthetes, chi-squared analyses, $P<.05$.

[a] Participants could nominate more than one area; percentages therefore do not add up to 100%.

[b] Eight non-synaesthetes were not asked about strengths and weaknesses.

Finally, 67% of synaesthetes claimed to have experienced precognitive phenomena (e.g. déjà vu, 'psychic' experiences). These experiences were reported as occurring frequently by 34% of individuals, and occasionally by 33%. In the general population, 60–80% of individuals report having experienced precognitive phenomena such as déjà vu, paranormal dreams, and 'out of body' experiences (Adachi et al., 2003). Thus, synaesthetes do not seem to be more likely to report precognitive phenomena than would be expected for the general population, contrary to suggestions based on anecdotal observations (Cytowic, 1989).

3.4. Analyses of synaesthetic colours elicited by letters, digits, and words

We turn now to data from 150 lexical-colour synaesthetes who completed two questionnaires, three months apart. First, we analysed the consistency of synaesthetic experiences at re-test, and compared this with data from the 45 non-synaesthetic controls who also completed two questionnaires, separated by one month. Second, we compared the colours elicited by each alphanumeric character across the synaesthete sample. Third, we analysed the colours associated with letters and digits by non-synaesthetes, as well as the colours used in children's books, and compared these with the synaesthetic colours reported by individuals in our sample. Finally, we explored some of the factors that may determine the synaesthetic colour of a word, such as its initial letter, its meaning, and whether it belongs to a sequence that follows a conventional order (e.g. Monday, Tuesday…)

3.4.1. Individual consistency of lexical-colour synaesthesia

The mean consistency of synaesthetic colour experiences elicited by letters and numerals after three months was 87% ($SD = 13$; median $= 92$), whereas for non-synaesthetes the consistency of responses after one month was 26% ($SD = 14$; median $= 23$). Synaesthetes were significantly more consistent than non-synaesthetes, $t(192) = 28.3$, $P < .001$. It is noteworthy that the consistency estimate for synaesthetes is less than 100%. This might be because the colours experienced by some synaesthetes actually change over time, or because synaesthetes' descriptions vary over time.

3.4.2. Group consistency of lexical-colour synaesthesia

We examined the frequency with which colours were elicited by each letter and digit across the sample of lexical-colour synaesthetes. To determine whether an item tended to elicit a specific colour, we calculated the frequency with which each colour was chosen for all letters (and separately, all digits), and constructed 95% confidence intervals (CI) around these mean values. To illustrate, the colour red was elicited by one or more letters for 11% ($SD = 9\%$) of the sample overall. Thus, if more than 29% of individuals experience red for any one letter (i.e. the mean $+2SD$), we can conclude that this is a statistically reliable association. This approach effectively normalises differences in the baseline frequency with which colours were reported by the group. Fig. 1 shows the distribution of colour responses of synaesthetes for each of the eleven colour categories.

Fig. 1a clearly illustrates that often the first letter of a colour name reliably elicited that colour. For example, a significant percentage of synaesthetes experienced red for 'R'

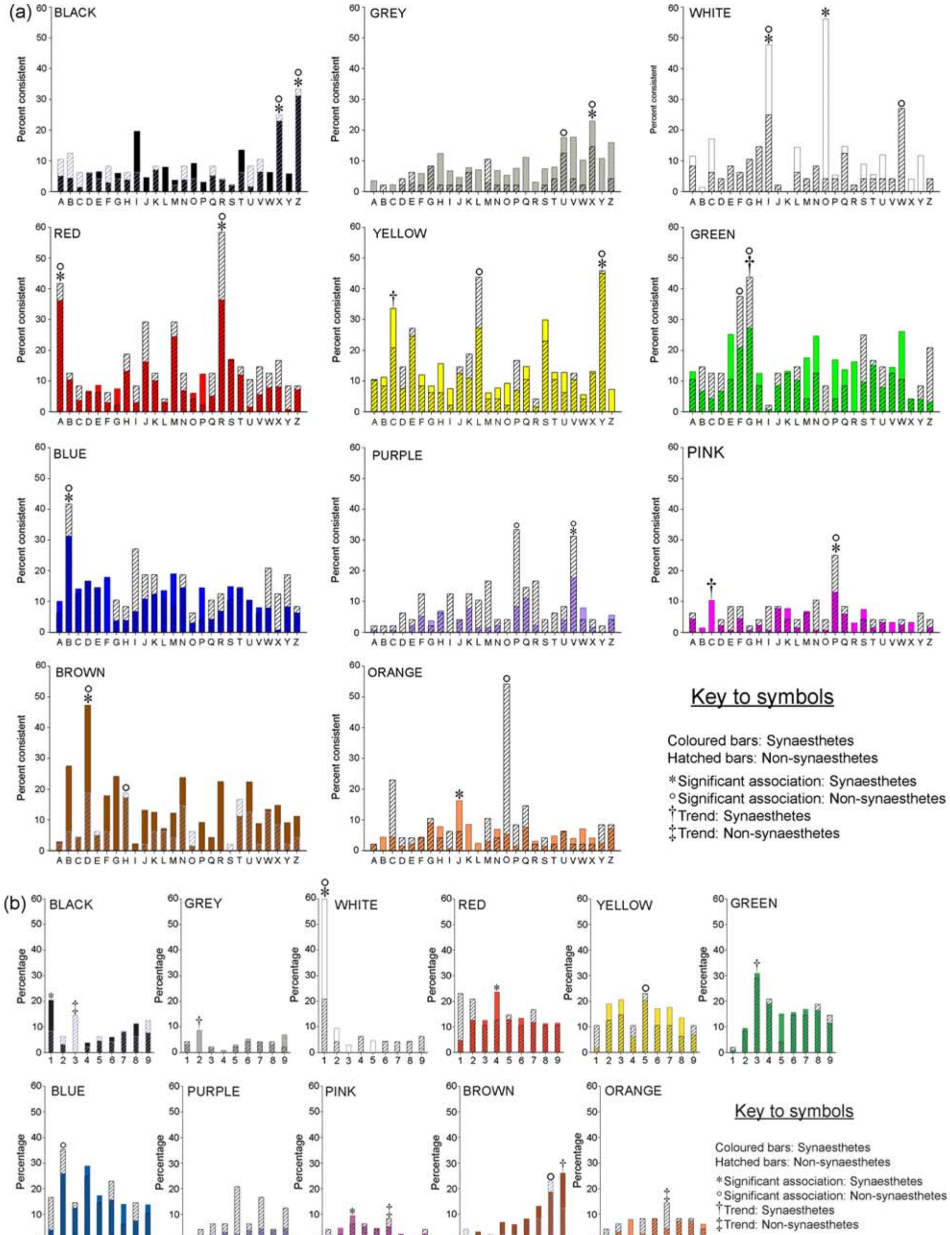

Fig. 1. Consistency of colours for the sample of lexical-colour synaesthetes (coloured bars) and non-synaesthetes (hatched bars) for each of the eleven basic colour terms. (a) Letters of the alphabet. (b) Digits 1 to 9. Significant associations are defined as cases in which the percentage is more than two standard deviations above the mean for that colour (95% confidence interval), calculated separately for synaesthetes and non-synaesthetes. Trends are cases in which the percentage is within one percent of the upper limit of the 95% confidence interval. There were no significant values below the mean frequency for any colour for either group.

(36%), yellow for 'Y' (45%), and blue for 'B' (31%); similarly, many synaesthetes saw pink for 'P' (13%) and violet for 'V' (classified as purple; 18%). There were, however, some notable exceptions. There was no significant association between orange and 'O' or brown and 'B'. Moreover, approximately half of all synaesthetes experienced white for 'O' and 'I' (56 and 48%, respectively). Similarly, 36% of synaesthetes experienced red for 'A', 47% experienced brown for 'D', and 16% experienced orange for 'J'. Some of these links may be due to the phonemic forms of the letters occurring within the relevant colour names. For example, /ai/ is a prominent phoneme in 'white', and /dz/ is a prominent phoneme in 'orange'.[5] Others may reflect phonemic–semantic links, such as 'D' and 'dark' brown or 'D'–dog→brown.

In his meta-analysis of previously published studies, Marks (1975) reported that "the vowel *a* predominantly aroused the colours red and blue, *e* and *i* tended to be yellow and white, *o* tended to be red and black, *u* was usually blue, brown, or black" (p. 308). In our sample, the colours for 'A' (red) and 'I' (white) are consistent with those reported by Marks (1975). The association of white with 'O' has also been reported before (e.g. Baron-Cohen et al., 1993; Day, 2005; Lay, 1896). On the other hand, several of the associations reported by Marks (1975) were not replicated in our sample. The reasons for these discrepancies are not clear, though we note that some of the studies included in the meta-analysis adopted different criteria for coding synaesthetes' colour experiences. In addition, the letter-colour correspondences suggested by Marks (1975) were not analysed statistically with respect to baseline rates of colour responses, and so it is not possible to determine their reliability.

Fig. 1b shows the percentage of individuals who reported particular colours for the digits 1–9. Most strikingly, 60% of synaesthetes in the sample experienced white for the digit '1', whereas a further 20% experienced black. Twenty-four percent of individuals saw red for '4' and 10% saw pink for '3'. There were no other significant associations.

3.4.3. Colour associations of non-synaesthetes

We analysed data from the non-synaesthetic controls in the same manner as that described for the synaesthetic sample. Recall that the non-synaesthetes were asked to associate a colour with each letter and digit. Our aim was to determine whether the particular colours experienced by synaesthetes for each item were consistent with the colour names given by non-synaesthetic controls for the same item. Figure 1 reveals some striking similarities between the colour responses of the two groups: the controls were more likely to associate black with 'X' and 'Z', grey with 'X', white with 'I', red with 'A' and 'R', yellow with 'Y', blue with 'B', violet (purple) with 'V', pink with 'P', and brown with 'D'. Of the 13 significant colour matches for synaesthetes, 11 were also apparent for non-synaesthetic controls (compare the coloured and hatched bars in Fig. 1a). Several other colour associations were made by non-synaesthetes that were unique to this group (e.g. white for 'W', orange for 'O'). For the digits, the only common colour response for

[5] From the International Phonetic Alphabet (International Phonetic Association, c/o Department of Linguistics, University of Victoria, Victoria, BC, Canada).

the two groups was white for ‘1’; several other reliable patterns were evident for the non-synaesthete group alone (see Fig. 1b).

3.4.4. What influences the associations between colours and alphanumeric characters?

The presence of common colour associations for synaesthetes and non-synaesthetes suggests that the formation of specific character-colour pairs may be influenced by a common set of experiences. Exposure to children’s books that use colours for letters and digits is one possible source of such associations. If coloured letters and digits in books influence the particular synaesthetic colours elicited by alphanumeric characters, we might predict some degree of consistency between the colours used in those books, on the one hand, and the colour experiences reported by synaesthetes on the other. To investigate this hypothesis, we examined two comprehensive collections of children’s books: The Australian Children’s Literature Collection [State Library of Victoria, Australia] and the Australian School Textbooks Collection [Deakin University, Australia].

The synaesthetes in our sample were born between 1914 and 1986. We therefore limited our investigation to children’s books available in Australia between 1900 and 1989. The final sample consisted of 136 books published between 1862 and 1989. (Many books available in Australia during the early 20th century were published much earlier in Britain). We were surprised to find that only 38 of these books contained coloured letters, or had prominent colour associations in the illustrations, such as single-colour objects or backgrounds for each letter. For simplicity, we call these ‘alphabet books’. Only 20 books had coloured digits or a single-colour illustration associated with each digit (‘number books’). Although colour printing was widely used in the 20th century, and coloured illustrations were common, many early books consisted of colour washes or single-tone printing throughout, rather than showing individually coloured letters and digits.

We analysed the consistency with which letters and digits were presented in particular colours in each of the two samples of books (alphabet and number). We adopted the same approach to scoring as that used for the colour experiences of the synaesthetes. In a significant percentage of the alphabet books, grey (8%) and white (8%) were associated with ‘E’. Similarly, red was associated with ‘A’ (43%), green with ‘H’ (24%) and ‘S’ (23%), purple with ‘P’ (9%), brown with ‘D’ (15%), and orange with ‘O’ (18%). The letter ‘I’ tended to be presented in white, or with white objects (7%), and purple tended to be associated with ‘V’ (8%), although neither of these associations reached statistical significance (within 1% of upper 95% CI). Interestingly, the colours associated with ‘A’ (red) and ‘D’ (brown) in the children’s alphabet books were also the colours most often linked with these letters by both the synaesthetes and the non-synaesthetic controls. Both groups had significant associations for ‘I’ (white) and ‘V’ (purple) which were present as trends in the alphabet books. For the number books, the only significant associations were ‘7’ with black (13%) and ‘9’ with blue (30%), neither of which was evident in synaesthetes or controls.

We also examined whether the colour experiences of any individual synaesthete could be predicted by the colours of letters and digits in each of the children’s books. Our reasoning was that if any of our synaesthetes had possessed a particular alphabet book as a child, we should find (at least) one book in the sample whose letter-colour pairings match those experienced by that individual. To do this, we took the synaesthetic colour for the letter ‘A’ for each individual synaesthete and compared it with the colour for ‘A’ depicted in each of the alphabet books; this same procedure was undertaken for all 26 letters and 9 digits. To ensure a reasonable sample of coloured characters, only books in which more than half the letters or digits were coloured (including coloured backgrounds and objects) were included. This yielded 26 alphabet books and 20 number books in total.

Of the 150 synaesthetes, only one individual had synaesthetic colours that were consistent with those in an alphabet book. This synaesthete had 77% consistency with the 26 letter colours from a single alphabet book (Christie, 1940s),[6] but could not recall having seen this book as a child. Four synaesthetes experienced colours for the digits 1–9 that were 78–100% consistent with the colours of the numerals in one of the number books (Noel, 1966). It is noteworthy that these colours were the same as those used in a method of teaching mathematics that was prevalent across much of the English-speaking world in the 1950–1960s. ‘Cuisenaire rods’ were used to teach students the concepts of basic mathematics. The rods consist of small blocks between 1 and 10 cm in length, with each unit of length associated with a unique colour (Trivett, 1959). Cuisenaire rods were officially introduced into Australian primary schools in 1964 and their use continued into the late 1970s. They may therefore have had an influence on the colours some synaesthetes and controls associate with numbers. We repeated the analyses with only synaesthetes born between 1950 and 1979 ($N=74$) to limit the sample to those individuals likely to have used Cuisenaire rods during their schooling. This analysis revealed an additional trend for ‘5’ to induce yellow, consistent with the colour of the ‘5’ in the Cuisenaire set.

To summarise, although there is some consistency between the colours used in alphabet and number books and those reported by our participants, overall there is little evidence to suggest that synaesthetic colours, or even colour associations, stem from exposure to colours used in children’s books. To our surprise there were relatively few children’s books published before 1989 that used coloured letters and digits, suggesting that other factors determine synaesthetes’ colour experiences for these stimuli. Our findings do not shed light on why synaesthetic colours occur for some individuals and not others. We *can* conclude, however, that many of the colour experiences of these individuals correspond to spontaneous colour associations in non-synaesthetes, suggesting a common foundation.

3.4.5. How do synaesthetic colours become linked to letters, digits, and words?

Most children learn the alphabet and basic counting at an early age, but do not learn to read and spell until the first years of primary school (Siegler, Deloache, & Eisenberg, 2003). Although most children can correctly name all the letters by six years of age (Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998), they still have difficulty identifying their *sounds* (Treiman, 2000). Many three-year olds can count up to 10 objects (Siegler et al., 2003), and know the distinction between words that are

[6] There is no publication date for this book, but experts at the State Library of Victoria estimated that it was published in the 1940s.

part of a number sequence and those that are not part of that sequence (Sarnecka & Gelman, 2004). In the current education system in Victoria (Australia), the first year of schooling includes learning to match written letters with their names and sounds, and basic number processes using digits (Victorian Curriculum and Assessment Authority (VCAA), 2000). In the second year, children are expected to use both words and digits to describe numbers (VCAA, 2000). Reciting other sequences, such as the days of the week and months of the year, is part of the first and second years of schooling, respectively (VCAA, 2000).

Synaesthesia tends to be elicited by items belonging to conventional sequences (e.g. letters, digits, days of the week, months of the year). In our sample, synaesthetes who experienced colours for just a small set of lexical stimuli tended to do so for days of the week, letters and digits, rather than for other item categories (e.g. animal names). This suggests that stimuli learned as part of a conventional sequence may be particularly important in the development of synaesthetic inducer-colour pairs. If this were the case, we would predict a difference in the way that synaesthetic colours are linked to sequential items compared with items that are not part of a sequence. Many of our synaesthetes reported that the first letter of a word determines its synaesthetic colour, and that most (if not all) words that start with that letter elicit the same colour. This implies that either letters and words with the same initial sound become linked to the same synaesthetic colour, or letters are linked to colours and then these generalise to words when spelling is learned. We investigated the relationship between the colour elicited by a word and the colour elicited by the initial letter of that word (hereafter 'initial-letter colour'). Based on our synaesthetes' reports, we predicted that in most cases a word would elicit the same colour as that of its initial letter. However, if sequences of words are a special category with respect to synaesthetic experiences, then colours induced by sequential items (e.g. days of the week) should differ from the initial-letter colours. Fig. 2a shows the percentage of synaesthetes for whom the colour evoked by a word was the same as the initial-letter colour. Sequences (days of the week, months of the year) were less likely to induce the same synaesthetic colour as the initial letter than were non-sequential words (people's names, place names and occupations), $t(24.98) = -4.34$, $P < .001$ (corrected for lack of equality of variances). These results suggest that sequential stimuli, such as days of the week, may become linked to synaesthetic colours independently of their initial letters, whereas the synaesthetic colours elicited by other categories of words depend primarily on the initial letter.

The age at which a word is first learned may be important in the apparent uniqueness of sequential stimuli. The days of the week sequence is learned at an earlier age than the months of the year sequence (VCAA, 2000). Consistent with this, we found that the synaesthetic colours induced by days of the week were less likely to be predicted by the initial letter than were those induced by months of the year, $t(17) = -2.72$, $P < .05$, suggesting that the age of acquisition may indeed be an important factor in determining the synaesthetic colours induced by words.

Finally, we tested the hypothesis that synaesthetic colours become associated with words through a process of generalisation from sequences of stimuli learned early in childhood to other, non-sequential stimuli. If this is correct, then the colours induced

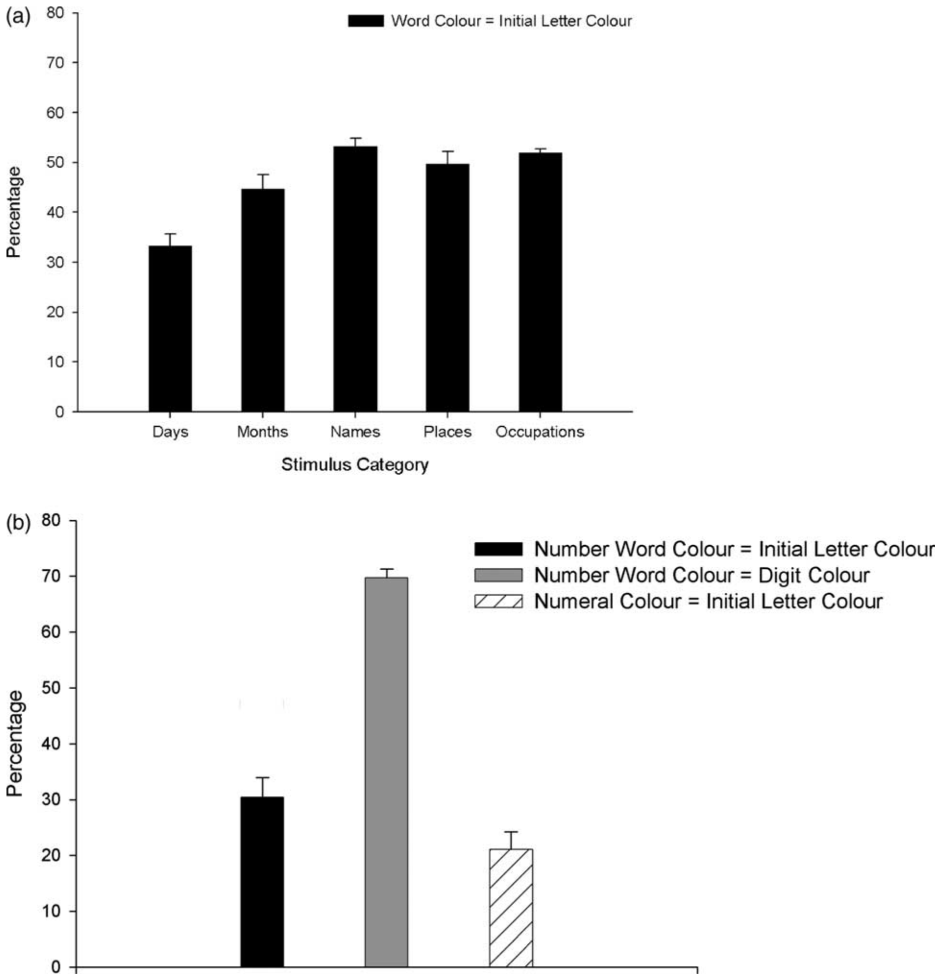

Fig. 2. Comparison of synaesthetic colours induced by words and initial letters. (a) Percentage of the sample whose synaesthetic colours for words were consistent with the colours induced by the initial letters. Separate bars for two well-known sequences (days of the week, months of the year) and three non-sequential categories (names, places, occupations). (b) Percentage of the sample with matching synaesthetic colours for number words and initial letters (e.g. *One*→'O' colour; black bar), number words and digits (e.g. *One*→'1' colour; grey bar), and digits and initial letters (e.g. *1*→'O' colour; hatched bar).

by digits and number words should be consistent, rather than the number word colour matching its spelling, which is typically learned later (VCAA, 2000). As can be seen in Fig. 2b, digits and number words (e.g. '1' and 'one') are significantly more likely to elicit the same synaesthetic colours than are initial letters and number words (e.g. 'O' and 'one'); and initial letters and digits (e.g. 'O' and '1') are significantly less likely to induce the same colour than initial letters and number words (one-way

ANOVA: $F(2,24)=80.68$, $P<.001$; post-hoc Tukey's tests: $P<.05$ for all comparisons). For most synaesthetes, then, the colour elicited by a number word is more consistent with the colour induced by the relevant digit than with the colour elicited by the initial letter of the word.

The results presented here suggest that although synaesthetic colours are generally determined by the first letter of a word, this is not true for words that are part of a well-known sequence, such as days of the week. The 'special' status of sequential stimuli may reflect the early age at which these words are learned. We also found that the colour induced by a number word tends to be the same as the colour induced by the relevant digit, rather than by its initial letter. This may occur because digits are learned earlier and denote the same concept of numerosity as number words.

3.4.6. Are synaesthetic colours determined by the meaning of a word?

In the previous section, we found that words denoting a number are more likely to be coloured by their meaning (or concept of numerosity) than by their spelling, suggesting that meaning influences synaesthesia. To further examine the influence of word meaning we tested whether synaesthetic experiences induced by *colour names* were more likely to be determined by the meaning of the word than its spelling. In addition, we selected 10 nouns for which more than 50% of the non-synaesthetes gave the same colour association (e.g. *cow*→brown). Fig. 3 shows the percentage of synaesthetic colours that were consistent with either the colour denoted by the word meaning, or with the initial letter of the word. The synaesthetic colours elicited by colour names were more consistent with the meaning of the word than with its initial-letter colour, $t(20)=-11.14$, $P<.001$; in contrast, the 10 non-colour words evoked colours that were more consistent with the initial-letter colour, $t(11.13)=4.22$, $P<.01$ (corrected for inhomogeneity of variance).

These results demonstrate that for most synaesthetes, the synaesthetic colour induced by a colour name is determined by the meaning of the word. To illustrate, one synaesthete wrote: *"The word 'blue' is definitely blue even though it should be brown because of the brown 'b'"*. Other authors have described lexical-colour synaesthetes for whom the synaesthetic colour induced by a colour name does not match the meaning (Gray et al., 2002). These authors argue that this so-called 'alien colour effect' provides evidence against associative learning as the basis of synaesthesia, as there would be many normal associative learning opportunities for a synaesthetic child to learn the visual colour experience to which the colour word is applied. While this account may hold for synaesthetes who experience the 'alien colour effect', our results suggest that for the majority of lexical-colour synaesthetes, the colour denoted by the word itself is dominant, suggesting that associative learning does influence the synaesthetic colour evoked by colour names. This pattern may also hold for words denoting objects with a strong canonical colour. For example, MD wrote: *"'banana' should be dark blue and black* [due to the letters]*, but it's yellow."* When there is no unambiguous colour for a given object word (e.g. although 'brown' is a typical colour for a dog, not all dogs are brown), however, the synaesthetic colour is most likely to be determined by the initial letter of the word.

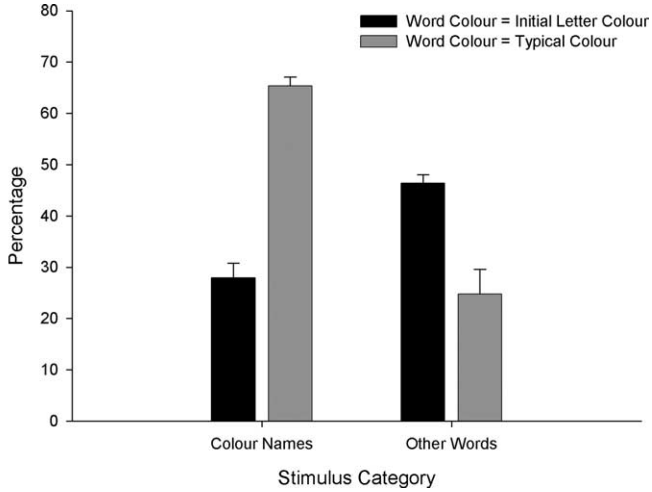

Fig. 3. Synaesthetic colours induced by colour names and nouns for which non-synaesthetic controls identified typical colours. Percentage of the sample with matching synaesthetic colours for the words and the initial letter colours (black bars) versus the words and the typical colours (grey bars), plotted separately for colour names and nouns with typical colours.

4. Discussion

The main purpose of our study was to explore synaesthetic experiences in a large group of adults with synaesthesia. We characterised the demographic and personal characteristics of 192 synaesthetes, and investigated the relationships between inducers and synaesthetic colours in a subgroup of 150 individuals with lexical-colour synaesthesia.

Our data suggest that synaesthesia occurs in 1 in 1150 females (0.087%) and 1 in 7150 males (0.014%). Although proper epidemiological sampling is necessary to obtain true prevalence rates, it is worth noting that our estimate is very similar to that reported previously in a smaller sample[7] (Baron-Cohen et al., 1996). Around a third of synaesthetes had at least one biological relative with synaesthesia, consistent with observations that synaesthesia tends to run in families (Bailey & Johnson, 1997; Baron-Cohen et al., 1996; Galton, 1883). Importantly, however, approximately half the sample did not have a biological relative with synaesthesia, suggesting that environmental factors must also be critical in the development of the phenomenon.

By far the most common form of synaesthesia is that in which letters, digits, and words induce colours. For most synaesthetes, these colours are induced by seeing, hearing, or thinking about letters or numbers, suggesting that relatively few such individuals have *exclusively* grapheme-colour or phoneme-colour synaesthesia. We suggest that in future studies, synaesthetes who experience colours for letters, digits and words should be termed

[7] Taking into account gender, and assuming an equal readership of females and males.

lexical-colour synaesthetes, unless it can be demonstrated that their colours arise only for visual or auditory inducers.[8]

Contrary to previous claims (Cytowic, 1996), we found that synaesthetes are no more likely to be left-handed or prone to 'precognitive' experiences than individuals in the general population. Interestingly, however, our data suggest that synaesthetes are more likely to be artistic, though obviously we cannot determine causality in this apparent relationship.[9] Our findings also suggest that synaesthesia can aid memory, consistent with previous single-case studies (Luria, 1969; Smilek, Dixon, Cudahy, & Merikle, 2002), and that synaesthetes as a group are more likely to be poor at mathematics and navigation than non-synaesthetes (Cytowic, 1996). These self-reported weaknesses are unlikely to be due to gender differences in these skills (e.g. Dabbs, Chang, Strong, & Milun, 1998; Gallagher et al., 2000; Moffat, Hampson, & Hatzipanteli, 1998), because the ratio of males to females in our synaesthetes was similar to that in our non-synaesthetic controls. It will be important for future investigations to determine whether these subjective cognitive differences can be verified objectively. One other finding from the first section of the study is worthy of particular mention. Many individuals experienced synaesthesia for non-native languages, regardless of their fluency in those languages. Often these non-native languages were learned during teenage years, or on reaching adulthood, when synaesthetic colours were already firmly established in English. The colours induced by non-native languages appeared to follow the letter-colour rules established in the native language, regardless of whether the alphabet was shared. This supports our proposal that synaesthetic colours acquired early in development can generalise to stimuli learned at a later stage.

In the second part of our study, we focused on 150 individuals with lexical-colour synaesthesia. The synaesthetes in this sample were highly reliable over time in their reports of inducer-colour pairs, consistent with previous anecdotal and empirical observations (e.g. Baron-Cohen et al., 1993, 1987; Dresslar, 1903; Galton, 1883; Ginsberg, 1923). There was also a striking consistency in the colours induced by specific letters and digits across the sample as a whole. Although the particular synaesthetic colour induced by a letter cannot be predicted for a given individual, our data provide evidence that synaesthetic character-colour pairs are not entirely idiosyncratic. Non-synaesthetes asked to associate colours with alphanumeric characters provided many of the same pairs, suggesting that common experiences may underlie the links evident in the two groups. Of the consistent letter-colour associations in synaesthetes and non-synaesthetes, most shared the initial letter of a colour name (e.g. 'R'→red), or had common phonemes (e.g. 'I'–/ai/→white; 'J'–/dz/→orange). Other associations may have arisen from semantic links (e.g. 'D'–dog→brown), or from exposure to letters or digits printed in specific colours in preschool or primary school charts. We did not find strong evidence that the colours used in children's books were the source of either group's colour associations. For a small number of synaesthetes, the colours induced by digits reflected the colours used for

---

[8] We note the difficulty in demonstrating objectively that sensory stimulation, and not the resulting activation of the conceptual representation of the stimulus (i.e. thought), is responsible for inducing a synaesthetic colour.

[9] Having synaesthesia may predispose one toward being artistic; alternatively, people with an artistic predisposition may be more likely to have synaesthesia. It is also possible that some other factor or set of factors, as yet unknown, may influence the development of both synaesthesia and artistic talents.

teaching numerical skills in Australian schools (Cuisenaire rods), and there are, of course, many other potential learning experiences involving coloured letters and digits.

There may be an underlying rule that determines both synaesthetic colours and non-synaesthetic associations. For example, Marks (1975) demonstrated that the synaesthetic colours induced by vowels became brighter as the pitch of the spoken vowel became higher, similar to the way in which non-synaesthetes match a brighter light with a higher-pitch sound (Martino & Marks, 1999). This similarity suggests that the link between sound and visual experience in synaesthetes may reflect fundamental processes of sensory coding in the relevant modalities (Marks, 2000). However, the psychophysical properties of letters and digits are effectively independent of their lexical properties (e.g. a letter can be presented in various fonts, and spoken in various pitches and volumes; Marks, 2000). It therefore seems unlikely that cross-modal correspondences would determine the links between alphanumeric characters and the synaesthetic colours they elicit. Instead, the frequency of occurrence of letters, numbers and colour names may be important in determining inducer-colour pairs. *White*, which is the highest frequency colour word in English, is most commonly associated with the number 'one', which happens to be the highest frequency number word (Kucera & Francis, 1967). The association between 'white' and 'one' may therefore reflect their mutual status as high-frequency words or concepts. Similarly, *red* is the highest frequency colour word (excluding black and white), and it was elicited most often by the letter 'A', which is the highest frequency letter (Kucera & Francis, 1967). It is likely that multiple factors determine the particular colour associated with a letter, including the shape and sound of the letter, the words, objects, and colours with which it is commonly associated, and the frequencies of the letter and the colour name. Further studies are needed to tease apart the relative contributions of these factors.

Although it is not possible to predict the colours induced by all the letters and numbers for any given individual, the reliable patterns revealed in our data suggest that early learning is the primary influence on the specific inducer-concurrent pairs in lexical-colour synaesthesia. In this we do not mean that early learning is the *cause* of synaesthesia; rather, we propose that when there is a predisposition for synaesthesia (as determined genetically or otherwise), the particular inducer-concurrent pairs are likely to be influenced by early learning experiences to which both synaesthetes and non-synaesthetes are exposed. The question of *why* these associations lead to unique synaesthetic experiences in just a small proportion of the population remains to be answered. Perhaps the development of synaesthetic inducer-concurrent pairs is guided by similar principles to those that underlie language acquisition. Humans have an innate predisposition to acquire language, but normal language acquisition depends on the presence of experiential factors during a critical period of development, such as exposure to appropriate language and the ability to hear one's own voice (Doupe & Kuhl, 1999).

We speculate that the acquisition of permanent synaesthetic inducer-concurrent pairs is limited to a critical period in childhood, and that these form the basis for all subsequent synaesthetic experiences. Some forms of synaesthesia might arise much earlier in development (e.g. during infancy; Maurer, 1997), but synaesthesia induced by letters and digits is most likely to be consolidated in childhood. The notion of a critical period is supported by a study of the phoneme-taste pairs in a lexical-gustatory synaesthete, JIW

(Ward & Simner, 2003). In this study, detailed analyses revealed that JIW's synaesthetic tastes could be traced back to foods he had eaten regularly as a child; by contrast, there were very few synaesthetic concurrents for tastes that JIW had experienced for the first time as an adult (e.g. coffee).

Our results suggest that early synaesthetic links can generalise to other categories of stimuli. Synaesthetic colours appear to develop initially for sequences of stimuli that are learned early in childhood, such as the alphabet, the digits 1–9, and days of the week. Other words may then acquire colours based on their initial or component letters. This view is supported by the finding that digits and number words are more likely to evoke the same colours than are initial letters and number words (e.g. 'Two' is more likely to elicit the same colour as '2' than 'T'). Thus, for the majority of synaesthetes, the colours of number words are determined by meaning rather than by spelling. Children learn digits prior to number words (VCAA, 2000), suggesting that synaesthetic colours from one set of stimuli (digits) can generalise to related sets of stimuli (number words). Moreover, the synaesthetic colours reported for non-native languages, which were typically acquired after puberty in our sample, also tend to follow the colours elicited by the native alphabet. For KT, who learnt Greek as an adult, the synaesthetic colours elicited by the Greek alphabet were related to the form or sound of Roman letters. Similarly, Mills and colleagues (2002) reported that a native English-speaking synaesthete who learned Russian after puberty had colours for the Cyrillic alphabet that were all related to her colours for Roman letters.

As a final cautionary note, we wish to emphasise that the findings reported here are based on self-report measures, and so are susceptible to the limitations inherent in this approach. Further research is needed to determine whether there are objective differences between synaesthetes and non-synaesthetes in the skills and attributes assessed in our questionnaire. For example, are synaesthetes more skilled in art or just more likely to participate in artistic pursuits? Are synaesthetes worse at eye-hand coordination, mathematics, and direction finding than non-synaesthetes? Is there any objective evidence that synaesthetes have heightened acuity of the senses? If so, is this related to the synaesthetic experiences: do individuals with 'sound-colour' synaesthesia have more acute hearing or perfect pitch, and do individuals with 'smell-colour' synaesthesia have a more acute sense of smell? It will also be important for future investigations to address the broader theoretical issues raised by our study: What causes synaesthesia when there is no familial history? Is there a clear dichotomy between synaesthetes and non-synaesthetes, or do such 'synaesthetic' experiences exist along a continuum? Finally, in lexical-colour synaesthesia, what is the mechanism by which lexical stimuli evoke the vivid and involuntary colour experiences reported by synaesthetes? We hope our findings will stimulate investigation of these and other outstanding questions.

Acknowledgements

We wish to thank Jessica Edquist, Belinda Howard, Ester Klimkeit, Tracy Long, and Jonathan Payne for assistance in data collection, and Christian Nicholas, Mark Williams and Jamie Ward for comments on an earlier version of the manuscript. We also thank

Juliet O'Connor from the State Library of Victoria and Peter Macauley from Deakin University for their generous assistance. ANR is supported by an Australian Postgraduate Award. JBM is supported by grants from the Australian Research Council and National Health and Medical Research Council.

Appendix A. Relevant questionnaire items

A.1. Demographic information

- Sex
- Age
- Date of birth
- Occupation
- Interests/hobbies
- Handedness:
  - Which hand do you use to write with? Left Right Either
  - Are there any activities for which you prefer to use your non-writing hand?

A.2. Synaesthetic characteristics

- Describe your synaesthesia
- What kinds of things trigger or elicit your synaesthesia?
- Do these things always give the same experiences?
- How long have you had synaesthesia?
- How often do you experience your synaesthesia? (e.g. daily, weekly, monthly, occasionally)
- Are you able to control your synaesthesia (e.g. can you stop it happening, or make it happen if you wish)?
- Does attention or lack of attention seem to affect the vividness of your synaesthesia?
- Are there any circumstances when your synaesthesia seems stronger, clearer, longer lasting; or weaker, shorter (e.g. under the influence of alcohol, medication, caffeine, tobacco, other drugs, fatigue, stress, time of the day)?
- Do you remember anything in the past that may have triggered the development of your synaesthesia?
- Are there times when your synaesthesia is advantageous?
- Are there times when your synaesthesia is disadvantageous?
- Do any other members of your immediate family experience synaesthesia?
- If yes, describe your relationship (biological, by marriage or other; e.g. brother, aunt by marriage, etc).

A.3. Languages

- What is your first language?
- Do you speak any other languages?

If yes,
– What other languages do you speak?
– Are you fluent in your other languages?
- Do you experience synaesthesia with the other languages?

A.4. Medical history

- Have you had any illnesses that involved injury or infection of the brain (e.g. head trauma that resulted in unconsciousness; meningitis; epilepsy; stroke)?
- Do you get migraines? YES/NO
  If yes, how often, and are you on any medication for them (please specify)?
- Have you ever had any problems related to mental health (e.g. severe depression or anxiety)?
- Are there any ways in which you believe your senses are different to most other people?

A.5. Other personal characteristics

- Are you unusually good or bad at any particular skill that you know of?
- Do you experience unusual precognition, déjà vu, etc. on a regular basis? (Please indicate roughly how often).

References

Adachi, N., Adachi, T., Kimura, M., Akanuma, N., Takekawa, Y., & Kato, M. (2003). Demographic and psychological features of déjà vu experiences in a nonclinical Japanese population. *The Journal of Nervous and Mental Disease*, *191*(4), 242–247.

Australian Bureau of Statistics (2001). *Census of population and housing*. Canberra: Australian Government.

Bailey, M. E. S., & Johnson, K. J. (1997). Synaesthesia: Is a genetic analysis feasible?. In S. Baron-Cohen, & J. E. Harrison (Eds.), *Synaesthesia: Classic and contemporary readings* (pp. 182–207). Massachusetts: Blackwell, 182–207.

Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., & Bolton, P. (1996). Synaesthesia: Prevalence and familiality. *Perception*, *25*, 1073–1079.

Baron-Cohen, S., Harrison, J., Goldstein, L. H., & Wyke, M. (1993). Coloured speech perception: Is synaesthesia what happens when modularity breaks down? *Perception*, *22*, 419–426.

Baron-Cohen, S., Wyke, M. A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception*, *16*, 761–767.

Berlin, B., & Kay, P. (1969). *Basic color terms: Their universality and evolution*. Berkeley: University of California Press.

Christie, C. (1940s). *Animal ABC*. Digest Juvenile Productions: Melbourne.

Cytowic, R. E. (1989). *Synesthesia: A union of the senses*. New York: Springer.

Cytowic, R. E. (1996). Synesthesia: Phenomenology and neuropsychology. *Psyche*, *2*(10).

Cytowic, R. E. (1997). Synaesthesia: Phenomenology and neuropsychology. In S. Baron-Cohen, & J. E. Harrison (Eds.), *Synaesthesia: Classic and contemporary readings* (pp. 17–39). Massachusetts: Blackwell, 17–39.

Dabbs, J. M., Chang, E. C., Strong, R. A., & Milun, R. (1998). Spatial ability, navigation strategy, and geographic knowledge among men and women. *Evolution and Human Behavior*, *19*, 89–98.

Day, S. A. (2005). Some demographic and socio-cultural aspects of synesthesia. In L. C. Robertson, & N. Sagiv (Eds.), *Synesthesia: Perspectives from cognitive neuroscience* (pp. 11–33). New York: Oxford University Press, 11–33.

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

Doupe, A. J., & Kuhl, P. K. (1999). Birdsong and human speech: Common themes and mechanisms. *Annual Reviews in Neuroscience*, *22*, 567–631.

Dow, S. (1999). Colour-coded. *The Australian Magazine*, 18–21.

Dresslar, F. B. (1903). Are chromaesthesias variable? A study of an individual case. *American Journal of Psychology*, *14*, 308–382.

Gallagher, A. M., De Lisi, R., Holst, P. C., McGillicuddy-De Lisi, A. V., Morely, M., & Cahalan, C. (2000). Gender differences in advanced mathematical problem solving. *Journal of Experimental Child Psychology*, *75*(3), 165–190.

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

Galton, F. (1883). *Inquiries into human faculty and its development*. London: Dent.

Ginsberg, L. (1923). A case of synaesthesia. *American Journal of Psychology*, *34*, 582–589.

Gray, J. A., Chopping, S., Nunn, J., Parslow, D., Gregory, L., Williams, S., et al. (2002). Implications of synaesthesia for functionalism. *Journal of Consciousness Studies*, *9*(12), 5–31.

Grossenbacher, P. G., & Lovelace, C. T. (2001). Mechanisms of synesthesia: Cognitive and physiological constraints. *Trends in Cognitive Sciences*, *5*(1), 36–41.

Humphrey, P. P., Feniuk, W., Perren, M. J., Beresford, I. J., Skingle, M., & Whalley, E. T. (1990). Serotonin and migraine. *Annals of New York Academy of Sciences*, *600*, 587–598.

Kessler, R. C., McGonagle, K. A., Zhao, S., Nelson, C. B., Hughes, M., Eshleman, S., et al. (1994). Lifetime and 12 month prevalence of DSM-III-R psychiatric disorders in the United States. *Archives of General Psychiatry*, *51*(1), 8–19.

Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence: Brown University Press.

Lay, W. (1896). Three cases of synaesthesia. *Psychological Review* , 92–95.

Luria, A. R. (1969). *The mind of a mnemonist*. London: Jonathan Cape Ltd.

Marks, L. E. (1975). On colored-hearing synesthesia: Cross-modal translations of sensory dimensions. *Psychological Bulletin*, *82*(3), 303–331.

Marks, L. E. (2000). Synesthesia. In E. Cardena, S. J. Lynn, & S. C. Krippner (Eds.), *Varieties of anomalous experience: Examining the scientific evidence* (pp. 121–149). Washington: American Psychological Association, 121–149.

Marks, L. E., & Odgaard, E. C. (2005). Developmental constraints on theories of synesthesia. In L. C. Robertson, & N. Sagiv (Eds.), *Synesthesia: Perspectives from cognitive neuroscience* (pp. 214–236). New York: Oxford University Press, 214–236.

Martino, G., & Marks, L. E. (1999). Perceptual and linguistic interactions in speeded classification: Tests of the semantic coding hypothesis. *Perception*, *28*, 903–923.

Mattingley, J. B., Payne, J. M., & Rich, A. N. Attentional load attenuates synaesthetic priming effects in grapheme-colour synaesthesia. *Cortex* [in press].

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

Maurer, D. (1997). Neonatal synaesthesia: Implications for the processing of speech and faces. In S. Baron-Cohen, & J. E. Harrison (Eds.), *Synaesthesia: Classic and contemporary readings* (pp. 224–242). Massachusetts: Blackwell Publishers Inc, 224–242.

Mills, C. B., Viguers, M. L., Edelson, S. K., Thomas, A. T., Simon-Dack, S. L., & Innis, J. A. (2002). The colour of two alphabets for a multilingual synesthete. *Perception* .

Moffat, S. D., Hampson, E., & Hatzipanteli, M. (1998). Navigation in a virtual maze: Sex differences and correlation with psychometric measures of spatial ability in humans. *Evolution and Human Behavior*, *9*, 73–87.

Noel, J. (1966). *All about 10*. Philograph Publications Ltd.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropyschologia*, *9*, 97–113.

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia—a window into perception, thought and language. *Journal of Consciousness Studies*, *8*(12), 3–34.

Rasmussen, B. K. (2001). Epidemiology of headache. *Cephalalgia*, *21*, 774–777.

Rich, A. N., & Mattingley, J. B. (2002). Anomalous perception in synaesthesia: A cognitive neuroscience perspective. *Nature Reviews Neuroscience*, *3*, 43–52.

Rich, A. N., & Mattingley, J. B. (2003). The effects of stimulus competition and voluntary attention on colour-graphemic synaesthesia. *NeuroReport*, *14*(14), 1793–1798.

Sagiv, N., & Robertson, L. C. (2005). Synesthesia and the binding problem. In L. C. Robertson, & N. Sagiv (Eds.), *Synesthesia: Perspectives from cognitive neuroscience*. New York: Oxford University Press.

Sarnecka, B. W., & Gelman, S. A. (2004). Six does not just mean a lot: Preschoolers see number words as specific. *Cognition*, *92*, 329–352.

Siegler, R., Deloache, J., & Eisenberg, N. (2003). *How children develop*. New York: Worth Publishers.

Smilek, D., Dixon, M. J., Cudahy, C., & Merikle, P. M. (2002). Synesthetic color experiences influence memory. *Psychological Science*, *13*(6), 548–552.

Snyder, S. H. (1986). *Drugs and the Brain*. New York: Scientific American Library.

Thomaides, T., Karagounakis, D., Spantideas, A., & Katelanis, S. (2003). Transcranial doppler in migraine attacks before and after treatment with oral Zolmitriptan or Sumatriptan. *Headache*, *43*, 54–58.

Treiman, R. (2000). The foundations of literacy. *Current Directions in Psychological Science*, *9*(3), 89–92.

Treiman, R., Tincoff, R., Rodriguez, K., Mouzaki, A., & Francis, D. J. (1998). The foundations of literacy: Learning the sounds of letters. *Child Development*, *69*(6), 1524–1540.

Trivett, J. V. (1959). The coloured sticks. *The New Scientist*, 1183–1186.

Victorian Curriculum and Assessment Authority (VCAA) (2000). *Curriculum and standards framework*. Victoria: State Government of Victoria.

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