

Searching for Shereshevskii: What is superior about the memory of synaesthetes?

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Some individuals with superior memory, such as the mnemonist Shereshevskii (Luria, 1968), are known to have synaesthesia. However, the extent to which superior memory is a general characteristic of synaesthesia is unknown, as is the precise cognitive mechanism by which synaesthesia affects memory. This study demonstrates that synaesthetes tend to report subjectively better than average memory and that these reports are borne out with objective testing. Synaesthetes experiencing colours for words show better memory than matched controls for stimuli that induce synaesthesia (word lists) relative to stimuli that do not (an abstract figure). However, memory advantages are not limited to material that elicits synaesthesia because synaesthetes demonstrate enhanced memory for colour per se (which does not induce a synaesthetic response). Our results suggest that the memory enhancement found in synaesthetes is related to an enhanced retention of colour in both synaesthetic and nonsynaesthetic situations. Furthermore, this may account for the fact that synaesthetic associations, once formed, remain highly consistent.

One of the most remarkable cases of superior memory on record is that of Shereshevskii (or S.), featured in Luria's (1968) popular book "The Mind of a Mnemonist". Luria's work with Shereshevskii spanned over 30 years and, during this period, Luria came to the conclusion that his memory "had no distinct limits . . . there was no limit either to the *capacity* of S.'s memory or the *durability of the traces retained*" (p. 11, emphasis retained). For example, he was able to remember complex and meaningless mathematical formulae and matrices of 50 digits after only a few minutes inspection. Moreover, he was able to recall them when retested 15 or 16 years later. There may be multiple causes of Shereshevskii's superior memory. In some situations,

Shereshevskii appeared to deliberately employ strategies known to aid memory such as forming visual associations and using the method of loci (i.e., remembering novel sequences by placing them along familiar points in a visualized route). However, many commentators, including Luria himself, have argued that there is good reason to suppose that it also reflects some innate characteristic that is not commonly found in others (e.g., Wilding & Valentine, 1997; but see Ericsson & Chase, 1982). High on the list of candidates for such an innate characteristic is the fact that Shereshevskii was noted to be synaesthetic. Whilst it is no longer possible to assess Shereshevskii's synaesthesia and the impact it may or may not have had on his memory, it is

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possible to study other synaesthetes in order to examine the extent to which superior memory is a characteristic of this condition. One can also investigate the nature of the underlying cognitive processes (e.g., encoding, storage, retrieval) that are affected by synaesthesia, with a view to formulating more detailed explanations of individual differences in memory ability. These are the aims of the present study.

Synaesthesia is a developmental condition that is established early in life and has a hereditary component (e.g., Ward & Simner, 2005). It consists of involuntary perceptual experiences that are elicited by stimuli that would not, in most other people, elicit such a response (for reviews, see Hubbard & Ramachandran, 2005; Rich & Mattingley, 2002). Some of the most common types include experiencing colours in response to words (particularly names of days and months), letters, and numbers (Simner et al., in press). Experiences other than colour are found but are apparently more rare (e.g., Ward & Simner, 2003; Ward, Simner, & Auyeung, 2005). The description of Shersheshesvskii suggests at least six different types of synaesthesia elicited by at least four different types of trigger (or “inducer”) and experienced in at least three different sensory modalities (or “concurrents”; following the terminology of Grossenbacher & Lovelace, 2001). This is summarized in Figure 1. Synaesthesia is

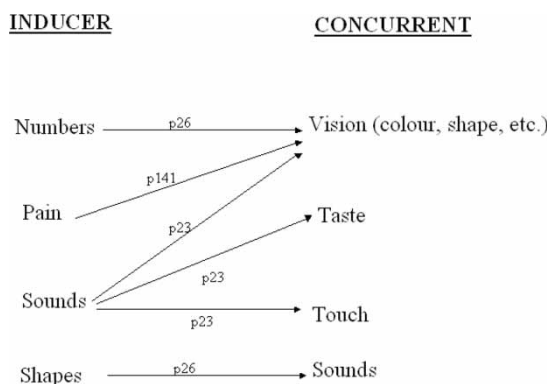


Figure 1. Luria (1968) alludes to at least six different types of synaesthesia in *Shereshesvskii* (page numbers provide links to the relevant evidence).

generally not considered harmful for health or disruptive for cognition. Nevertheless, synaesthetes may well have an altered cognitive profile of strengths and weaknesses. Memory is sometimes reported to be a strength, and numerical cognition is often reported as a weakness (e.g., Cytowic, 1989; Rich, Bradshaw, & Mattingley, 2005).

There have been two recent case studies of memory performance in known synaesthetes. The first of these, by Smilek, Dixon, Cudahy, and Merikle (2002), reports “C.”, who came to the attention of the researchers during a psychology class on memory in which she showed near-perfect performance. The impact of C.’s synaesthesia on her digit recall was assessed by presenting her with matrices of coloured digits that were coloured either congruently or incongruently with her synaesthesia. C. showed a significant benefit in recalling the congruent matrix relative to the incongruent matrix. This pattern was not observed for controls. Although C.’s memory was within normal limits on the learning phase relative to controls, her ability to retain digits in the long term (48 hours) was clearly superior. Her retention of stimuli that do not induce synaesthesia (abstract shapes) over 48 hours was normal rather than superior. This study thus provides convincing evidence that synaesthesia can have a direct bearing on memory performance and can lead to superior memory for material that induces synaesthesia. It is not possible, however, to make more general claims about the relationship between memory and synaesthesia. Note that C. first came to the attention of researchers because of her superior memory and not because of her synaesthesia. As such, the extent to which superior memory may be a general characteristic of synaesthetes (not specifically selected on memory criteria) is unknown. Moreover, the nature of the cognitive process is largely unknown. What is it about experiencing colours for digits that enables them to be better retained?

A second case study of memory in a synaesthete was reported by Mills, Innis, Westendorf, Owsianiecki, and McDonald (2006). Their participant was, as far as we know, selected on the basis of her synaesthesia rather than on the basis

of reports of superior memory. Her ability to learn and retain verbal information was nevertheless superior in paired associate learning (pairing novel Christian and surnames) and in list learning (the Rey Auditory-Verbal Learning Test). She was, however, no better in remembering a complex figure that does not induce synaesthesia (the Rey Complex Figure Test). Mills et al. explained this pattern in terms of synaesthesia providing an extra cue that can guide memory retrieval (similar accounts were proposed by Cytowic, 2002, and Luria, 1968). For example, a synaesthete may not remember a name but may remember that it was blue. This fact may then serve as a cue to guide strategic memory operations (e.g., by generating names beginning with blue letters). This suggestion is clearly related to Paivio's (1969, 1995) dual-coding theory of memory. This theory states that memory performance for verbal material can be enhanced if it is also encoded as a mental image (e.g., by forming a visual image of the concept at the learning phase). Encoding an event in multiple memory systems may render the memory more durable and protect against forgetting.

There are alternative accounts to the dual-coding theory. Synaesthetes could have superior memory for synaesthesia-inducing material because synaesthetes have superior memory for colour per se (i.e., irrespective of whether the colour is or is not synaesthetically elicited). Whereas the dual-coding hypothesis predicts that synaesthetes and controls will perform normally on tests of colour memory (because colours rarely induce extra sensations in synaesthetes),¹ the "superior memory for colour" explanation predicts that synaesthetes should outperform controls on these tests. These hypotheses are contrasted in the present study. In doing so, we are guided by the three different ways in which memory can be said to be superior (following Wilding & Valentine, 1997). These are listed below.

1. Rapid acquisition of material under control conditions.
2. Acquisition of an unusually large quantity of material in a measured time.
3. Long-term retention of an unusually large quantity of material acquired under control conditions.

EXPERIMENT 1

The aim of Experiment 1 was to examine whether synaesthetes are indeed more likely to report that their memory is better or even "photographic" and to assess what techniques they tend to use for memorization.

Method

Participants

A sample of 46 synaesthetes and 46 controls took part in this experiment. The sample of synaesthetes comprised 34 women and 12 men, with an age range of 22 to 78 years and an average age of 42.9 years. The control sample comprised 34 women and 12 men with an age range of 22 to 59 years and an average age of 33.9 years. The synaesthetes had previously contacted our research group to take part in synaesthesia research (rather than memory testing), whereas the control participants were specifically invited to participate in a memory experiment (although there was no mention of superior memory). The synaesthetes all reported colour experiences from processing verbal material (i.e., reading/hearing words, letters, and digits). Some reported additional types of synaesthesia that were not specifically investigated. None reported that colours act as inducers of synaesthesia. The authenticity of their synaesthesia was established using a measure of test-retest consistency over at least a 2-month period (range = 2–13 months;

¹ A case of synaesthesia in which colour induces sound was briefly mentioned by Baron-Cohen, Burt, Smith-Laittan, Harrison, and Bolton (1996) and was featured in the 1993 BBC Horizon documentary "Orange Sherbert Kisses". We are currently investigating this case and one other. Others have suggested that colours can implicitly activate representations of number (Cohen-Kadosh et al., 2005; Knoch, Gianotti, Mohr, & Brugger, 2005).

average = 5.3 months) for a list of 55 digits, letters, and words (adapted from Baron-Cohen, Harrison, Goldstein, & Wyke, 1993). The consistency measure was based on verbal colour descriptions. The synaesthetes had an average consistency of 94% (range = 79–100%). Previous research on a different sample of controls has found a consistency of 35.5% ($SD = 13.8$) when assessed over a 2-week test–retest period (reported in Simner et al., 2005). Each synaesthete lies beyond a 2-standard-deviation cutoff ($p < .05$) based on the control distribution of scores.

Procedure

Synaesthete and control participants were asked about their memory ability and memory strategies using the following three questions:

1. How would you describe your memory?
 - a. Better than average
 - b. Average
 - c. Worse than average
2. Would you describe your memory as “photographic”?
 - d. Yes
 - e. No
3. How would you describe the way in which you remember a phone number? (please underline the most applicable answer)
 - f. Saying the number over and over again to yourself
 - g. Remembering by the pattern of colours you experience when seeing the number
 - h. Breaking the number into chunks or sets of numbers
 - i. Taking a “mental picture” of the number
 - j. Writing down the number

Other, please specify

In addition, the synaesthetes (but not the controls) were asked whether they consider their synaesthesia to be causally linked to their memory performance. The question was as follows:

“Would you say that your synaesthetic experiences help you to remember things?”

They were required to give only a yes/no answer.

Results and discussion

The results are summarized in Figure 2. The majority of synaesthetes rate their memory as

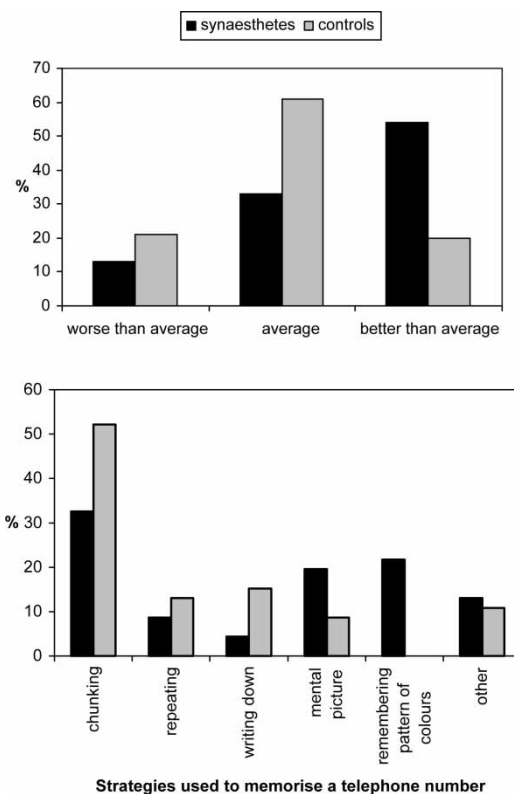


Figure 2. Synaesthetes are more likely to self-report better than average memory than are controls (top) and are more likely to report using visual strategies when memorizing a phone number (bottom).

“better than average”, while the majority of control subjects describe their memory as “average”, $\chi^2(2) = 12.06$, $p < .005$. A large proportion of the synaesthetes (70%) believe that synaesthesia is a help to their memory. When memorizing a telephone number, controls report relying to a greater extent on encoding strategies such as chunking, repeating, and writing a number down, whereas synaesthetes are more likely to use visual-imagery-based strategies such as forming a mental picture and remembering the number by the pattern of colours experienced, $\chi^2(5) = 17.27$, $p < .005$. The “other” category was mainly selected by individuals who described using rhythmic or arithmetic techniques, described that repetitive dialling of the telephone number would ensure that they would remember it, or

were unable to select a principal memorizing strategy. It is to be noted that participants may also use hybrid strategies even though, in this instance, they were asked to describe a single dominant strategy. There was no difference in the number of synaesthetes (45.6%) and controls (39.1%) who believed their memory to be photographic, $\chi^2(1) = 0.401$, *ns*. This may be because the synaesthetes regard their memory as “better” rather than exceptional, or because they have islands of enhanced ability rather than globally better memory. Both of these interpretations are consistent with the objective tests reported in subsequent experiments.

EXPERIMENT 2

Experiment 2 consists of a number of objective tests of memory that were carried out on a group of lexical-colour synaesthetes and matched controls in a single testing session. By incorporating a wide range of different tests we aimed to establish which aspects of memory, if any, were superior. Different types of material (e.g., spoken words, digits, abstract figure, colours) were contrasted with immediate learning versus recall after a delay. Although tasks were not exactly matched to each other (e.g., in terms of number of learning attempts etc.), they were chosen because they had previously been found to avoid floor and ceiling effects, thus enabling a wide range of abilities to be assessed.

The justification for choosing the Rey Auditory-Verbal Learning Test and the Rey Figure Test was that it enabled a comparison between verbal and visual memory. Only the former induces synaesthetic sensations. Synaesthete M.L.S. had previously been shown to be superior on the verbal but not on the visual test (Mills et al., 2006). The justification for using sets of matrices containing congruent and incongruently coloured digits was to replicate the findings of Smilek et al. (2002). Is superior memory a general feature of synaesthesia or restricted to a few cases? It is to be noted that we used smaller matrices (27 items instead of 50) and fewer initial learning phases (two instead of

four) due to time constraints. However, we gain statistical power by considering 16 synaesthetes rather than 1. This research was extended in a novel way by asking the question: Do memory differences for the matrices reflect the fact that they are coloured—that is, irrespective of whether the colours derive from synaesthesia? To assess this, participants were also given matrices of coloured squares to remember. If a difference between synaesthetes and controls is found on colour matrices it suggests that the difference in memory may be related to memory for colour *per se* rather than synaesthetic induction (an alternative possibility that colours could implicitly induce digits is discussed later). To follow up on this suggestion, a separate task was devised in which participants were shown a precise hue and were subsequently asked to recognize that hue amongst two similar distractor colours. Given that colours do not explicitly induce synaesthesia we would predict that synaesthetes would be better on this task if they have superior memory for colour but not necessarily if having an “extra” sensation was the basis for enhanced memory. Finally, a test of colour perception (Farnsworth-Munsell hue test) was administered to ensure that participants could discriminate between the hues used in the memory test. We had no *a priori* prediction concerning differences between synaesthetes and controls in this particular test.

Method

Participants

The participants consisted of 16 synaesthetes and 16 control participants matched for age (synaesthetes = 38.4 years, range = 22–60; controls = 38.6 years, range = 22–59), sex (12 females and 4 males in each group), and mean number of years in education (synaesthetes = 16.5 years, range = 11–24; controls = 17.2 years, range = 13–21.5). The participants consisted of a subset of those reported in Experiment 1 who happened to live in the London area and were available for testing. They were considered to be representative of the larger sample reported in Experiment 1. For the synaesthetes, 9 reported better than average

memory, 4 reported average memory, and 3 reported worse than average memory (the figures for controls being 4, 9, and 3, respectively). All synaesthetes reported experiences of colour induced by verbal material including spoken and written words, digits, and letters. In all instances, words were coloured by one or more dominant letter (e.g., first letter) within the word, and, hence, all words tended to be coloured.

Procedure

Each participant was tested in a separate session lasting approximately 90 minutes. The session was organized as follows, and the specific details of each test are described below:

1. Digit and colour matrices learning phase—25 min.
2. Rey Auditory–Verbal Learning Test—10 min.
3. Farnsworth–Munsell colour perception test—15 min.
4. Rey Complex Figure copying—5 min.
5. Rey Auditory–Verbal retest—5 min.
6. Farnsworth–Munsell memory test—15 min.
7. Rey Complex Figure recall—5 min.
8. Recall of digit and colour matrices—10 min.

Rey Auditory–Verbal Learning Test (RAVLT) and Rey Complex Figure Test (RCFT). The RAVLT consists of a list of 15 nouns (List A), which are read aloud by the experimenter and which the participant must immediately recall in any order (Spree & Strauss, 1998). The same list is repeated 5 times in total with free recall following each repetition. A second list of 15 nouns (List B) is then read to the participant, and this must be immediately recalled in any order. List B acts as an interference trial. After recalling List B, the participant is then required to recall List A without it being presented again by the experimenter. Following a filled delay of 20 min the participant is also asked to recall List A without it being presented again. An additional phase was added in this experiment. Participants were asked to recall any words that they remembered in a surprise retest two weeks later (only List A was scored because

no participant recalled more than one item from List B). The retest was administered by e-mail.

The RCFT consists of an abstract diagram, which participants are asked to copy on to a blank sheet of A4 paper within 5 minutes (Spree & Strauss, 1998). Following a filled delay of 20 minutes, participants were presented with another blank sheet of paper and were asked to reproduce the figure from memory. No time limits were imposed for the recall test. Scores were obtained using the standardized scoring system accompanying the test, in which the presence of all components of the diagram yields a maximum score of 36 points.

Digit and colour matrices. Detailed colour descriptions of photisms for digits 0–9 were obtained from the synaesthetes (all experienced colours from digits). Two matrices of digits were tailored to each participant's synaesthetic experiences such that in one matrix the digit–colour pairings were congruent with their synaesthesia, and in another matrix they were incongruent. For the congruent condition, an effort was made to match the colours exactly, given that synaesthetes typically report precise hues. Both matrices contained 27 numbers, and, in all but one case, nine single digits appeared in each table three times (synaesthete S.A. experiences only the digits 1–7 in unambiguous colouring; for this particular participant digit tables therefore only contained digits 1–7). One matrix was 9×3 in shape (“landscape”), and the other was 3×9 in shape (“portrait”). This was done to minimize confusion between the matrices at a subsequent recall phase. The assignment of congruency and matrix shape was counterbalanced across participants (i.e., for half the participants 9×3 was congruent, and for the other participants it was incongruent). The individual matrices used for each synaesthete were randomly assigned to one of the control participants.

A third matrix was prepared that consisted of coloured squares rather than digits. There were 27 squares to remember (in a 3×9 array), which consisted of 9 different focal colours (red, yellow, blue, green, orange, purple, pink, brown, and

grey). The same colours and stimulus were used for all participants given that we are interested, in this instance, in the ability to remember the locations of colours that are not synaesthetically induced.

The same procedure was used for each of the three matrices in turn. The three matrices were always presented in the order digit–colour–digit. The order of the congruent/incongruent digit matrices was counterbalanced across participants. Participants were instructed to study a matrix for 2 min in order to commit as many digits/colours as possible to memory. The matrix was removed, and participants were given a 2-min recall period in which they were asked to write as many digits (or colour names) as they could remember into a blank 9×3 or 3×9 matrix. Participants were then shown the same matrix of digits/colours again for 2 min, followed by another 2-min recall period. After an hour filled with other activities they were shown blank matrices (but not the initial digit/colour matrices) and were asked to recall as many of the items as possible within 2 min. The blank matrices in the retention phase were presented in the same order as they were originally shown.

Farnsworth–Munsell Colour Perception Test. The Farnsworth–Munsell apparatus is a palette of different hues with identical luminance. The hues are presented in the form of coloured caps that when arranged correctly form a regular, circular, colour series transforming from one hue to another. These colour series are presented in four different trays, each containing 23 or 24 colours and each showing a distinct colour transformation. The procedure for each tray is as follows. The caps are taken out of the tray and are arranged on the table in front of the participant. Two colour caps are given to the participant, which represent the two end points of the colour sequence (e.g., a red and a yellow cap). The participant is then given 2 min to arrange the remaining caps so that they form an ordered colour series (e.g., red through orange through yellow). The correct ordering of the hues can be identified by the experimenter from the numeric coding on the underside of each cap. The score for each colour is calculated

by considering its deviation from the correct sequence. For example, consider a correct ordering such as 4–5–6. Colour number “5” has a score of 2 because it is 1 unit from 4 and 1 unit from 6. An incorrect ordering such as 2–5–9 would yield a score of 7 for colour “5” because it is 3 units from “2” and 4 units from “9”. The error score is the difference between the actual score obtained and the expected score based on flawless ordering. The same procedure was used for each of the four trays, the order of trays being randomized across participants.

Farnsworth–Munsell Colour Recognition Memory Test. The Farnsworth–Munsell palette was also used for a colour recognition memory test. Five colour targets were selected from each of the four trays. Distractors were selected as differing from the target by 4 or 8 hues, as identified by the numeric coding on the underside of each cap. A colour interval of 4 hues for the memory test was selected as it was thought that the 4-hue difference was perceivable, but would ensure that the task would be difficult enough to avoid ceiling effects. For example, if these hues were numbered 55, 59, and 63, the target cap may have been the number 55, which would have represented the lowest numbering of the colour options, with distractors differing by 4 and 8 hue shades. If, however, the target was 59, the target would represent the middle hue of the colour options, with distractors differing by 4 hues on either side. A total of 20 different colours were shown to the participants to remember, and 40 further distractor colours were used. Pilot testing suggested that the task is particularly hard. Therefore the 20 items to remember were presented in series of 4 colours followed by immediate testing (there was no delay component). Participants were instructed to remember very specific shades of colour. In the encoding phase, the four caps were presented for 5 s each, one at a time. Following this, they were shown the same caps again (in the same order) but each was paired with two distractors of a similar hue. They were required to choose exactly the same hue that they had first encountered.

Results and discussion

Rey Auditory-Verbal Learning Test (RAVLT) and Rey Complex Figure Test (RCFT)

The results from individual recall attempts at all the stages of the RAVLT are shown in Table 1. Each of the different recall phases of the experiment were treated as separate levels ($N = 9$) of a factor. A 2×9 analysis of variance (ANOVA) was conducted with participant group (synaesthete vs. control) as the second factor. The results show that synaesthetes do have a memory advantage for these stimuli: main effect of participant group, $F(1, 30) = 5.16$, $p < .05$. There was a main effect of the recall phase, $F(1, 30) = 97.25$, $p < .001$, which is consistent with a profile of learning and subsequent forgetting. However, there was no interaction between the two, $F(1, 30) = 1.00$, ns , $p = .096$. This suggests that the advantage of synaesthetes over controls was found across most of the recall phases. There was a trend for the synaesthetic advantage to be minimal on the very first learning attempt.

The results of the Rey Complex Figure Test are summarized in Figure 3. A 2×2 mixed ANOVA revealed a significant effect of test phase, $F(1, 30) = 141$, $p < .01$, no significant effect of group, $F(1, 30) = 0.52$, and no significant interaction between test phase and participant group, $F(1, 30) = 0.521$.

In summary, the results suggest that synaesthetes have enhanced memory in tests of verbal memory (in which synaesthesia is induced) relative to tests of memory for an abstract visual figure (in which synaesthesia is not induced).

Digit and colour matrices

The data for the digit and colour matrices are analysed and reported separately. The data from the two immediate learning trials are collapsed into a single score, to contrast with the retention score in which recall does not immediately

follow presentation of a matrix. The digit matrices were analysed in a $2 \times 2 \times 2$ mixed design with congruency (congruent vs. incongruent) and recall phase (learning vs. retention) as within-subject factors and participant group (synaesthete vs. control) as a between-subjects factor. The results are summarized in Figure 4. The ANOVA revealed a significant effect of recall phase, $F(1, 30) = 82.69$, $p < .001$, no significant effect of participant group, $F(1, 30) = 2.10$, no significant effect of congruency, $F(1, 30) = 0.895$, and no congruency-group interaction, $F(1, 30) = 0.307$. Similarly, no interactions between phase and group, $F(1, 30) = 2.280$, phase and congruency, $F(1, 30) = 0.257$, or congruency, phase, and group, $F(1, 30) = 1.922$, were found. In short, not only did we fail to find a memory advantage for synaesthetes, but we also failed to find an effect of congruency on memory performance.

Our results failed to replicate the effect of congruency on digit matrix recall demonstrated by Smilek et al. (2002). One explanation is that C.'s difficulty with incongruent stimuli may be due to a failure to adopt an appropriate strategy on her first encounter. Smilek et al. (2002) only report data from the first learning attempt although C. was given four attempts to learn it. Thus, the extent to which C. can develop strategies to overcome her initial "block" for encoding these incongruent stimuli is unknown.² The debriefing of our synaesthetes suggests that the presence of either a congruent or an incongruent stimulus could engender a variety of reactions. One synaesthete stated: "I was cross that they were in the wrong colour, and I couldn't get past being cross." However, other synaesthetes stated that incongruence did not affect their recall, as during encoding incongruent digits were simply mentally translated into their correct colours. Other synaesthetes became distracted by the congruent displays, appearing to spend more time enjoying the digits

² C. is also known to differ from many other synaesthetes in that she projects her photisms onto the surface of a page when reading (Dixon, Smilek, & Merikle, 2004). The only known "projector" in our sample had, in fact, the worst memory of the 16 synaesthetes tested (e.g., see Figure 7). On the digit matrices he recalled the position of 8 and 11 digits (out of 27) on the first congruent and incongruent trials, respectively.

Table 1. Performance by synaesthetes and controls on various components of the Rey Auditory-Verbal Learning Test

	List A					List B			
	1	2	3	4	5	Immediate	20 min	2 weeks	
Syn	8.5 (2.28)	11.8 (1.94)	13.7 (1.14)	13.9 (1.36)	14.4 (1.15)	7.8 (2.41)	13.8 (2.18)	13.8 (1.91)	7.4 (3.95)
Control	8.2 (1.83)	11.4 (2.03)	12.6 (1.50)	13.1 (1.31)	13.0 (2.03)	6.7 (2.06)	12.2 (2.23)	12.1 (1.84)	5.4 (3.36)

presented in the appropriate colour than attempting to memorize them.

The results of the colour matrix experiment were more clear cut and are summarized in Figure 5. A mixed 2×2 ANOVA revealed a significant effect of recall phase, $F(1,30) = 15.45$, $p < .001$, and no significant effect of participant group, $F(1,30) = 2.720$, but a significant interaction between participant group and testing phase was found, $F(1,30) = 6.579$, $p < .02$. Independent t tests revealed no significant difference between participant groups in the learning phase of the experiment, $t(30) = 0.848$, but a significant difference between participant groups in the retention phase, $t(30) = 2.11$, $p < .05$. This demonstrates that memory advantages found in synaesthetes may not be restricted to synaesthesia-inducing material but may be linked, instead, to the retention ability of the affected perceptual modality (i.e., the modality of the concurrent).

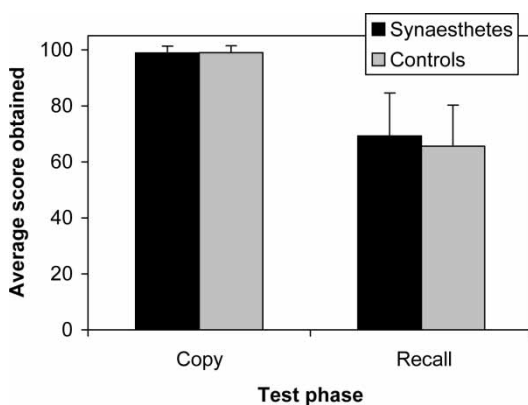


Figure 3. The performance of synaesthetes in copying and recalling the Rey complex figure does not differ from controls. (Error bars show 1 SD.)

Farnsworth–Munsell colour perception and colour recognition memory

Figure 6 shows average scores obtained in tests of colour discrimination and colour memory. The Farnsworth–Munsell Hue Test computes an error score based on the deviation from the expected ordering (it is not a percentage error). The performance on the recognition memory test is expressed in terms of percentage error. A better performance in both tests is therefore reflected in a lower score. Synaesthetes significantly outperform controls both in the test of colour perception, $t(30) = 2.266$, $p < .05$, and in the test of colour recognition memory, $t(30) = 2.982$, $p < .01$.

Given this pattern of results, one might wonder whether the synaesthetes perform better on the memory test because they, but not the controls,

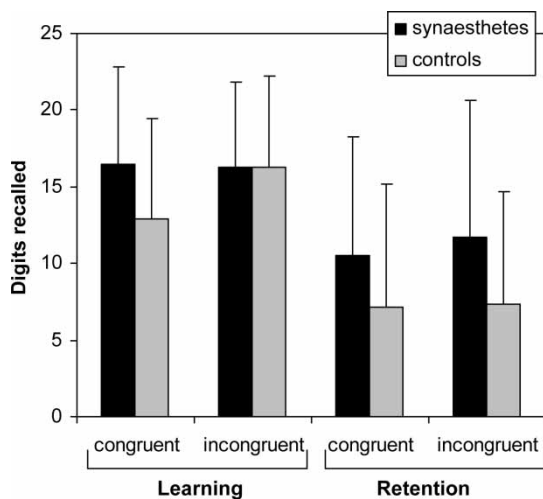


Figure 4. The ability to learn and retain matrices of digits that are coloured either congruently or incongruently with the synaesthetes' photisms. (Error bars show 1 SD.)

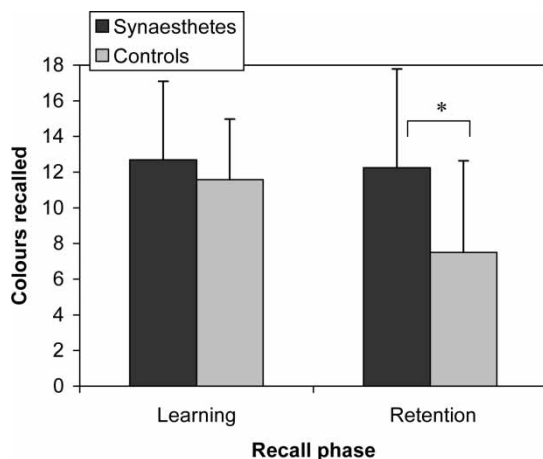


Figure 5. Synaesthetes show an enhanced ability to retain in memory a matrix of coloured squares.

could perceive the differences between the target colour and its distractors. This is unlikely to be the case. The control participants had an average error score of 65, which means that they could discriminate colours 0.76 hues apart ($= 65/85$),³ and even the worst performing participant could discriminate colours 2.3 hues apart. By contrast, the targets and distractors in the colour

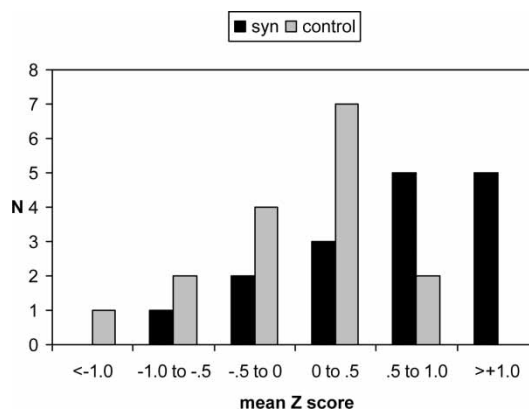


Figure 7. The distribution of averaged Z scores taken from 16 controls and 16 synaesthetes over 8 tasks: initial learning of the first 5 Rey lists; 2-week retention of Rey list; learning of the digit matrices (collapsed across congruency); retention of the digit matrices (collapsed across congruency); Rey figure; Farnsworth–Munsell colour memory; colour matrices learning; colour matrices retention.

recognition memory test were either 4 or 8 hues apart. As such, we are confident that all participants could perceive the difference between targets and distractors in the memory test. It appears as if synaesthetes have a general processing

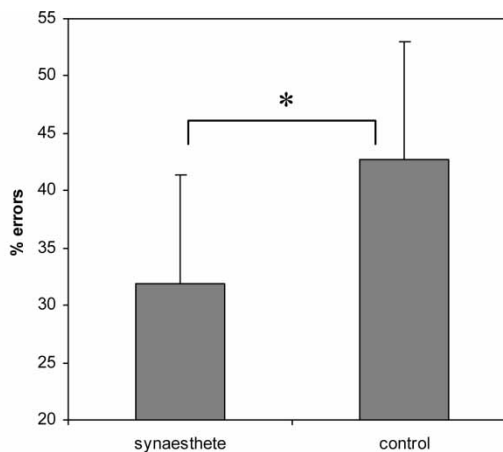
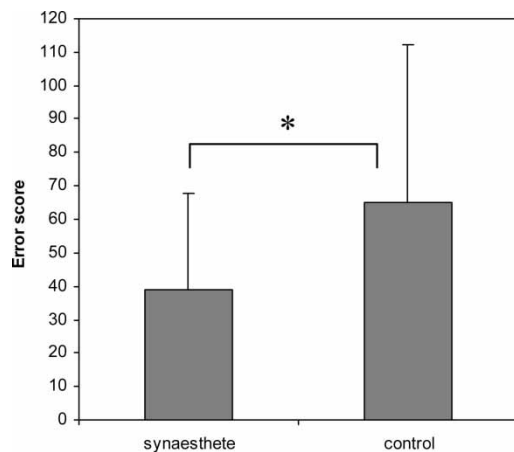


Figure 6. Synaesthetes outperform controls both in tests of colour perception (left) and in tests of colour recognition memory (right) for precise hues. (Error bars show 1 SD.)

³ Note that the error score is computed from 85 pairwise differences between adjacently ordered hues.

advantage for colours that manifests itself on both tests of perception and tests of memory. Possible explanations for this novel finding are considered in the General Discussion.

GENERAL DISCUSSION

The aim of this study was to investigate to what extent superior memory was a general feature of synaesthesia in which verbal material elicits colours, and to characterize this difference in terms of cognitive mechanisms within the memory system. The findings may be summarized as follows:

1. Synaesthetes tend to subjectively report better memory.
2. Synaesthetes show a memory advantage for material that induces synaesthesia relative to material that does not (Rey Auditory-Verbal vs. Rey Complex Figure Test).
3. The advantage for remembering synaesthesia-inducing material may be related to an enhanced ability to remember and perceive colour (colour matrices and Farnsworth-Munsell based tests). Enhanced memory is by no means restricted to synaesthesia-inducing material.

Comparisons with previous research

Before attempting a theoretical account of this pattern of data, it is important to compare these findings with those previously reported in the literature. The three most closely related accounts are those of Shereshevskii (Luria, 1968), C. (Smilek et al., 2002), and M.L.S. (Mills et al., 2006). Shereshevskii appears to have a superior memory for a wide variety of materials and is superior in terms of rapid acquisition, amount acquired, and amount retained. It is doubtful that our search has found a latter-day equivalent of Shereshevskii but,

of course, without direct comparisons it is impossible to be certain. Given that memory performance varies along a continuum, the point at which a given individual can be said to have "superior memory" is somewhat arbitrary. Wilding and Valentine (1997) have developed one method for comparing individual memory performance across a wide range of tasks by computing an average Z score (relative to a control sample) from a number of tasks. This meta-analysis was applied to all the memory tasks described here, and the results can be found in Figure 7 (note the similarity to Figure 2 based on the subjective memory assessment of a much larger sample).⁴ Five of our synaesthetes have a mean Z score greater than +1.0, and it is reasonable to label these individuals as having "superior memory" (but with the caveat that they are the tail end of a skewed normal distribution). The largest Z scores on individual subtests were typically for the colour matrices and/or the retention of verbal material (digit matrices or lists). Unlike Luria's account of Shereshevskii, we do not have a detailed understanding of how superior memory manifests itself in everyday situations for these individuals. One of the highest scorers, A.J.M., has, however, taken part in a number of other studies over the years. He has told us that he sometimes remembers the birthdays and mobile phone numbers of casual acquaintances and that they find it disconcerting that he is able to retain this personal information over long periods of time. When asked whether he could remember previous dates of visiting the University, he was able to quickly and accurately recall the date 20 August 2002 (retained for a period of over 2 years), and he felt he could recall others if given time.

Synaesthetes who possess superior memory may differ in interesting ways from other individuals with superior memory purely as a result of extensive training. People who have trained their memory do not have observable structural differences in their brains, although functional magnetic resonance imaging reveals a pattern of functional

⁴ Note that the expected mean is 0, and the expected standard deviation is $1/8 (= 0.125)$ because 8 objective measures of memory were pooled.

activity consistent with the particular strategy that they tend to adopt (i.e., the visuo-spatial "method of loci", Maguire, Valentine, Wilding, & Kapur, 2003). Synaesthetes are likely to possess more innate differences that manifest themselves in structural differences in the brain (although these are yet to be documented). Synaesthetes, such as Shereshevskii, who embark on the path of training their memory, are likely to find themselves at an extra advantage. Whilst synaesthesia may enhance memory, synaesthesia plus training may lead to truly exceptional memory. One prediction of our research is that superior memory in synaesthetes (when it is found) is likely to be most apparent for the retention of information, whereas for most nonsynaesthetic memory experts it is the learning rather than retention of information that sets them apart (Wilding & Valentine, 1997). Similar conclusions were reached by Smilek et al. (2002) and Mills et al. (2006). The only sense in which C. and M.L.S. could be said to be superior was in terms of their retention of information over the long term. C. was in normal limits on the first trials of learning the digit matrices, and M.L.S. showed no initial advantage on the first trial of the paired associate task.

The one aspect of previous research that we were unable to replicate was the memory advantage for congruent over incongruent stimuli reported by Smilek et al. (2002). Our results suggest that there are large idiosyncratic differences in encoding strategies used by synaesthetes. Moreover, synaesthetes who have trained their memory by making extensive use of their synaesthesia to memorize may show much stronger interference effects from incongruent stimuli than synaesthetes who have not trained themselves in this manner (for another example of a synaesthete to whom this might apply, see Azoulay, Hubbard, & Ramachandran, 2005).

Theoretical considerations

The first set of explanations that we need to consider is whether the pattern of results could be an artefact. That is, do the intergroup differences

reflect something other than synaesthesia itself? In our opinion, these explanations are inadequate but they should nonetheless be considered openly. First, the sample of synaesthetes tested may not be representative. However, our larger questionnaire study revealed a similar profile. Furthermore, it is unclear why, if self-selection was the main factor, that synaesthetes should have self-selected on the basis of good colour memory and good RAVLT, but not on the basis of good Rey Figure memory or good digit matrices, or on the basis of globally good memory. Despite the limitations of the present study, the sample is clearly more representative than single cases selected on the basis of known superior memory. Secondly, the advantages might reflect better verbal memory per se unrelated to synaesthesia (or better left-hemisphere memory). This is a difficult explanation to discount, and it is rather circular. The synaesthetes tested here do not have purely verbal cognition in the way that it is normally understood because words, digits, and even inner speech are associated with visual experiences. Thus, it is hard if not impossible to test verbal skills independently of their synaesthesia. It may, however, be possible to test this in other forms of synaesthesia (e.g., if music, but not words, triggers colour). Finally, the differences might reflect random differences in colour-processing ability unrelated to synaesthesia (e.g., the presence of an additional cone type in some females, Neitz, Kraft, & Neitz, 1998). Whilst we did not test for this, we consider it unlikely given that the samples were sex matched and that the effect of a fourth cone type is rarely apparent on the Farnsworth–Munsell test (Jameson, Highnote, & Wasserman, 2001).

The second set of explanations to consider can be conveniently grouped into encoding-type explanations. A simple dual-coding explanation (e.g., based on Paivio, 1969) predicts superior memory for synaesthetes in situations in which verbal material elicits visual experiences (e.g., Rey lists) because two codes are encoded rather than one. This theory does not predict the observed differences in colour matrices and colour recognition memory without additional assumptions. The

dual-coding explanation can account for this if one makes the further assumption that coloured stimuli in synaesthetes also trigger a verbal code (in the absence of actual synaesthetic experiences induced by colour). Maybe synaesthetes recode colours as verbal descriptions either covertly or overtly. On debriefing, two of our synaesthetes reported using an overt back-translation strategy for remembering the colour matrices but it is unlikely that the strategy gave them any advantage. Their scores ranked 14th and 29th (out of 32) for the learning phases and 16th and 22nd (out of 32) for the retention phase.

It has recently been suggested that synaesthetes may covertly activate digits when presented with colours in tasks such as quantity judgement of coloured stimuli (Cohen-Kadosh et al., 2005) and production of random colour sequences (Knoch et al., 2005). It is hard to discount the suggestion that similar processes are operating in the experiments described here, but the effects would be expected to be restricted in scope. Covert back-translation may only be effective in those situations in which the colour is coincidentally similar to a grapheme colour (perhaps unlikely for the limited colours used in the Farnsworth–Munsell test). Further research into synaesthetic colour perception is needed, taking into account known grapheme–colour correspondences. However, the present study is the first empirical demonstration of differences in colour perception and colour memory in synaesthetes, and any explanation offered will be tentative.

It is certainly possible that the presence of stable grapheme–colour associations has an impact on the internal structure of colour space. It has been suggested that linguistic labels (e.g., colour names) are needed in order to categorize colours that vary along a perceptual continuum (Davidoff, 2001). Cross-cultural differences in the number of colour names has an impact on both colour perception and colour memory (e.g., Roberson, Davies, & Davidoff, 2000). In synaesthetes, the presence of grapheme–colour associations may effectively increase their colour vocabulary from “red”, “green”, and so on, to include “5-coloured”, “D-coloured”, and so on. The increase in colour

terms could possibly result in a more fine-grained structuring of colour space. This is a plausible explanation of some of the observed differences between synaesthetes and controls. It could apply equally well to theories that assume back-translation (verbal + visual dual coding) or theories that assume that differences in the internal representation of colour alone may be sufficient (which we term storage accounts).

The third explanation to consider is a storage account. On balance, this is the explanation favoured here although further empirical demonstrations are needed. Put simply, synaesthetes may have a better capacity for retaining colour (at least in those synaesthetes in whom colour is the primary experience). This strikes us as a more parsimonious explanation than assuming that colours covertly back-translate to verbal labels, and these implicit verbal codes somehow enable better performance on tasks such as remembering the location of colours in a matrix or deciding which of three precise hues was seen before. An increased ability to retain colour offers a straightforward description of the data and also accounts for other observations in the literature. For example, it explains why reduced forgetting (rather than initial learning) is the cardinal feature of superior memory in synaesthetes (Mills et al., 2006; Smilek et al., 2002). The ability to retain colour information is also likely to lead to enhanced perceptual discrimination due to differences in the structuring of colour space (as already discussed).

We also speculate that an increased capacity to retain colour may be a partial explanation of synaesthesia itself. Almost all synaesthesia researchers make use of the fact that synaesthetic experiences are highly stable over time but there are few, if any, theoretical explanations for why this might be. It is possible that cross-modal links between, say, sound and vision are more likely to be stabilized into reliable (and perceptually real) associations in synaesthetes whereas, in other individuals, only more general trends can be observed (e.g., higher pitch and lighter colour, Marks, 1974, 1975; Ward, Huckstep, & Tsakanikos, 2006a). The claim is not that

synaesthetes deliberately learn such colour associations but that naturally occurring correlations between, say, colour and sound are more likely to be retained in perceptual memory in synaesthetes. Once retained, associations between sounds/phonemes/graphemes and colour may be hard to unlearn (e.g., Gray et al., 2002). In a few rare cases, the origin of the colour associations can be traced back to known coloured letter sets (Hancock, 2006; Witthoft & Winawer, 2006) although experience with coloured letters per se cannot be the sole explanation for synaesthesia. Other studies have shown that new colour associations can become established when a synaesthete learns a second alphabet in either childhood or adulthood (Mills et al., 2002; Rich et al., 2005; Witthoft & Winawer, 2006) and that synaesthetic colours can be transferred from letters to musical notation (Ward, Tsakanikos, & Bray, 2006b). These studies are consistent with the notion that an enhanced ability to retain colour will be an important aspect of any theory of synaesthesia. Further studies are needed to unequivocally demonstrate whether changes in colour cognition are an epiphenomenon of having synaesthesia that induces colour, or whether changes in colour cognition is more causally implicated in synaesthesia itself.

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