



Brief article

Enhanced associative memory for colour (but not shape or location) in synaesthesia



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ABSTRACT

People with grapheme-colour synaesthesia have been shown to have enhanced memory on a range of tasks using both stimuli that induce synaesthesia (e.g. words) and, more surprisingly, stimuli that do not (e.g. certain abstract visual stimuli). This study examines the latter by using multi-featured stimuli consisting of shape, colour and location conjunctions (e.g. shape A + colour A + location A; shape B + colour B + location B) presented in a recognition memory paradigm. This enables distractor items to be created in which one of these features is 'unbound' with respect to the others (e.g. shape A + colour B + location A; shape A + colour A + location C). Synaesthetes had higher recognition rates suggesting an enhanced ability to bind certain visual features together into memory. Importantly, synaesthetes' false alarm rates were lower only when colour was the unbound feature, not shape or location. We suggest that synaesthetes are "colour experts" and that enhanced perception can lead to enhanced memory in very specific ways; but, not for instance, an enhanced ability to form associations per se. The results support contemporary models that propose a continuum between perception and memory.

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1. Introduction

Synaesthesia is a developmental condition with an hereditary component, present from a young age and persisting throughout the lifespan (e.g. Ward, 2013). People with synaesthesia may experience numbers as coloured, words as tastes, or time as a spatial configuration. More formally, their synaesthetic experiences are said to be elicited, automatic, reliable, and percept-like in character. However, synaesthesia is not only an unusual way of experiencing the world – it is also linked to a particular profile of cognitive strengths and, possibly, weaknesses (Rich, Bradshaw, & Mattingley, 2005). People with synaesthesia report memory to be one of their strengths (Rich et al., 2005), and this is lar-

gely borne out by empirical testing (Rothen, Meier, & Ward, 2012). Experiencing verbal stimuli (letters, numbers, words) as visual patterns of colours, textures and word shapes, as in grapheme-colour synaesthesia, may be expected to enhance memory (relative to sex, age and education matched controls) because the encoded stimulus is richer relative to people without synaesthesia. Indeed, several studies (e.g. tests of free recall) using spoken or written words in grapheme-colour synaesthetes have reported a performance advantage (e.g., Radvansky, Gibson, & McNERNEY, 2011; Yaro & Ward, 2007). However, certain types of non-verbal, visual stimuli are also better remembered by grapheme-colour synaesthetes even though these stimuli do not evoke synaesthetic experiences. Indeed, on a standardised test battery of memory, the Wechsler Memory Scale (WMS), grapheme-colour synaesthetes had a significantly higher score on the visual subtests than the verbal subtests, although both were enhanced relative to controls (Rothen & Meier, 2010). As such, the presence of addi-

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tional experiences during memory encoding does not offer an adequate account of the existing data (although it could certainly be a factor when synaesthesia-inducing material is presented).

Aside from differences in memory ability, grapheme-colour synaesthetes show an atypical pattern of performance on tests of visual perception. One possibility is that the differences in memory ability stem from differences within the perceptual system, consistent with recent theories suggesting that there is no sharp division between memory and perceptual systems but rather divisions primarily according to the type of information represented (e.g. Graham, Barense, & Lee, 2010; Murray, Bussey, & Saksida, 2007). Synaesthesia is associated with both structural and functional differences within the brain (Rouw, Scholte, & Colizoli, 2011) and these structural differences between synaesthetes and neurotypical samples occur in regions linked to visual and spatial perception (e.g. the fusiform and parietal cortices) but, interestingly, not in regions traditionally linked to episodic memory (e.g. the medial temporal lobes). Increased grey matter is found in an area linked to colour perception (area V4; Banissy et al., 2012) and, behaviourally, synaesthetes perform better than controls on tests of colour perception (e.g. Banissy, Walsh, & Ward, 2009). Whilst we can say that synaesthetes are “colour experts” it must be borne in mind that this is part of a wider pattern of visual perceptual differences (Banissy et al., submitted for publication; Barnett et al., 2008) that are only now being explored in detail.

Could these differences in visual perception explain the enhancements in visual memory? Grapheme-colour synaesthetes outperform controls on recognition memory for precise colours (Yaro & Ward, 2007) and it is noteworthy that their highest performing subtest on the WMS was visual paired associates (Rothen & Meier, 2010) which involves pairing colours to abstract shapes. However, they do not outperform controls on all tests of associative memory. In the digit matrix task, participants must learn and then recall the location of digits within a grid (i.e. a form of object-location associative memory). Synaesthetes do not outperform controls on this task (Rothen & Meier, 2009; Yaro & Ward, 2007; but see Smilek, Dixon, Cudahy, & Merikle, 2002). However, direct comparisons across studies are hard to make because of different testing conditions, different task difficulties, different samples and sample sizes. The present study is conceptually related to both the visual paired associate task and the digit matrix task and involves memory for conjunctions of colours, shapes and locations. It uses a recognition memory paradigm in which participants view coloured shapes in different locations within a grid during the study phase. At test, they view both the old items (targets) and new items (distractors) created by recombining the original set of features and have to make an old/new discrimination. This enables distractor items to be created that differ from the target by one feature at a time – either shape, colour or location. If grapheme-colour synaesthetes have a selective ability to form colour associations then this should manifest itself as a selective reduction in false alarms when colour is the ‘unbound’ (i.e. swapped) memory feature.

2. Method

2.1. Participants

Sixty-four participants completed the study (28 synaesthetes, 36 controls). The average age of the synaesthetes was 39.6 years (S.D. = 16.5; 1 male) and that of controls was 36.1 years (S.D. = 14.7; 4 males), and this figure did not differ ($t(62) = .89$, N.S.). In the debrief, participants were asked to state their highest level of formal education level on a 4 point categorical scale (schooled to 16 years, schooled to 18 years, undergraduate, postgraduate). The two groups did not differ in education level ($\chi^2(3) = 6.53$, N.S.). For the synaesthetes, colour was an elicited experience (minimally from letters and numbers) but not an eliciting stimulus for synaesthesia (i.e. colour was not an inducer). The authenticity of grapheme-colour synesthesia was determined using a measure of internal consistency of grapheme-colour associations (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). The synaesthetes obtained a mean score of 0.77 on this test (S.D. = 0.24), indicative of synaesthesia (Eagleman et al., 2007). Ethical approval was given by the School of Psychology of the University of Sussex. Synaesthetes were recruited via an existing database of participants, and controls were recruited via advertisement and acquaintance.

2.2. Stimuli

The target stimuli consisted of 10 shapes, in 10 colours, and 10 locations. Examples of target and distractor stimuli are shown in Fig. 1 (rendered in greyscale) and the full set of coloured targets is appended as [Supplementary Online Material](#). The abstract shapes were created to be visually dissimilar from each other and not similar to familiar shapes/objects. The colours were chosen on the basis of being visually dissimilar to each other and also for being typical exemplars of colour categories. These were red, orange, yellow, green, light blue, navy blue, purple, pink, grey and black. The shape-colour pairs were presented within a 5×2 grid, each in a unique location. The assignment of shapes, colours and locations to each other was random and the same conjunctions were used for all participants.

In addition to the 10 targets there were 30 distractor stimuli. These consisted of 10 stimuli in which the colour was unbound with respect to the other two features (e.g. shape A + location A + colour B), 10 stimuli in which the shape was unbound (e.g. shape C + location A + colour A), and 10 stimuli in which the location was unbound (e.g. shape A + location D + colour A). This reassignment of features was random but fixed (i.e. it did not vary between blocks or across participants).

2.3. Procedure

The test consisted of four blocks of alternating study and test phases with the same stimuli repeated in each block (to measure learning). The stimuli were presented using Adobe Flash and the experiment was hosted online and conducted remotely. After providing demographics (age, sex) and giving consent, participants were instructed

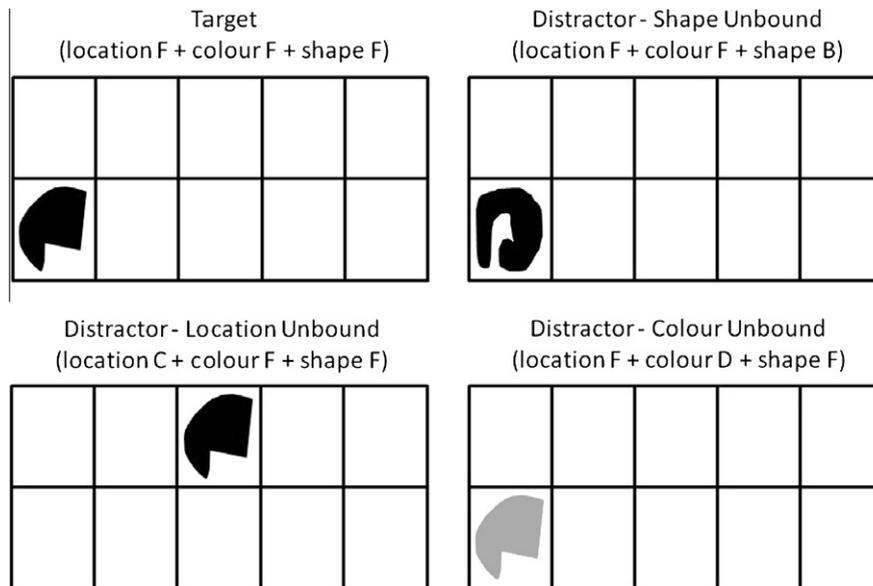


Fig. 1. An example of a target and the three types of distractor (note: the original stimuli were coloured but are shown here in greyscale).

that they were about to be presented with ten targets to remember and, following that, a test. They were instructed to remember the shape, colour and location. During the study phase, the 5×2 grid remained on the screen for the entire duration (the background was white). On a 20 in. monitor, the grid measured 21 cm by 5 cm and participants were advised to sit at a comfortable viewing distance. The coloured shapes would appear for 3 s in one of the locations and then disappear until all ten targets had been displayed in this way (with no delay between trials). Next, they were given instructions that they were about to be presented with more stimuli, and that they should only respond to say that they recognised an item if it was exactly the same as that presented in the learning stage (i.e. the same shape in the same colour in the same location). They were then presented with the ten targets and the ten distractors of each type (colour unbound, shape unbound, location unbound). The order of presentation of stimuli during study and test phases was fully randomised (i.e. varying across blocks and across participants). On each trial participants were asked whether they thought that the shape + colour + location combination was correct or incorrect by clicking the mouse on one of two radio buttons. Stimuli remained on the screen until a response was made, and the next stimulus appeared straight away. No feedback was given after each answer but participants had an opportunity to self-correct during the subsequent study phase. After completing the four blocks of study (comprising 10 trials each) and testing (comprising 40 trials each), participants were asked to provide details of their highest achieved level of education (as described earlier) and were then debriefed.

3. Results

Considering overall performance, synaesthetes had better memory performance as measured by d -prime (mean

[S.D.] for synaesthetes = 2.36 [1.02]; controls = 1.85 [0.91]; $t(62) = 2.10$, $p = .04$). This corresponds to a medium effect size of 0.54 (Cohen's d). There was no difference in bias measured via Criterion C (mean [S.D.] for synaesthetes = 0.00 [0.28]; controls = 0.09 [0.32]; $t(62) = 1.17$, N.S.).

The hit rates across groups and blocks are summarised in Fig. 2 (top). A 2×4 ANOVA was conducted on hit rates comparing group and block. There was a significant main effect of block ($F(3, 186) = 88.29$, $p < .001$; $\eta^2 = .32$) indicating that performance improved over time. There was a significant main effect of group ($F(1, 62) = 7.96$, $p = .006$; $\eta^2 = .05$) indicating that synaesthetes outperformed controls. There was no block \times group interaction ($F(3, 186) = .75$, N.S.); that is, the learning rates across groups are comparable. Synaesthetes start at a high level and maintain that benefit throughout. The increased hit rate is consistent with the notion that synaesthetes have an enhanced ability to bind certain basic visual features together into memory. However, given that these stimuli necessarily consist of a triple conjunction of features it is impossible to know whether certain associations within the triad are more tightly bound than others. Memory performance for the distractor stimuli speaks to that issue.

A $2 \times 3 \times 4$ ANOVA was conducted on the false alarms rates contrasting group as a between subject factor, and within subject factors consisting of the type of unbound feature (3 levels) and block number (4 levels). The results are summarised in Fig. 2 (bottom), collapsed across block for ease of exposition. There was a main effect of block ($F(3, 372) = 34.92$, $p < .001$; $\eta^2 = .12$) due to participants improving over time, but block did not interact with the remaining factors (including the triple interaction). There was also a main effect of feature type ($F(2, 372) = 11.00$, $p < .001$; $\eta^2 = .06$). For both groups, unbound locations were the easiest to reject and unbound shapes the hardest (location v. colour $t(63) = 2.21$, $p = .03$; colour v. shape

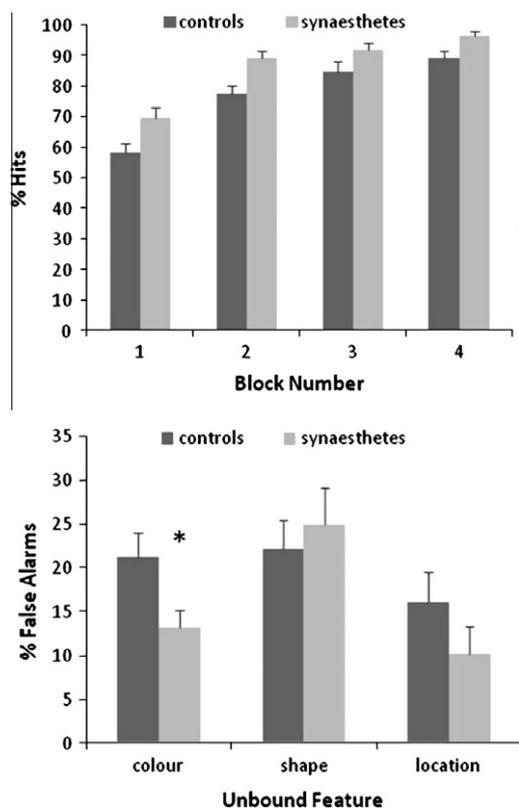


Fig. 2. A summary of recognition memory performance showing hit rate across blocks (top) and false alarm rates across the different types of distractor (bottom) for the two different groups. Error bars show 1 S.E.

$t(63) = 2.67, p = .009$). In contrast to the results for hit rate, there was no main effect of group on false alarms ($F(1, 62) = .91, N.S.$) but – crucially – there was a significant group X feature type interaction ($F(2, 372) = 3.26, p = .042; \eta^2 = .02$). Post-hoc t -tests establish that this is due to synaesthetes having a lower false alarm rate when colour is the unbound feature ($t(59.0) = 2.72, p = .027, \text{Cohen's } d = 0.55; \text{equal variances not assumed}^1$) but equivalent levels of false alarm rates when shape ($t(62) = .54, N.S.$) and location ($t(62) = 1.22, N.S.$) are the unbound features.

4. Discussion

This study adds further support to the idea that synaesthetes show a memory advantage compared to age, sex and education matched controls. Moreover, it suggests that the memory advantage extends to certain abstract visual stimuli and is not just found for stimuli that induce synaesthesia (i.e. words in the case of grapheme-colour synaesthesia), as has been more frequently documented (e.g. Radvansky et al., 2011). Unlike previous research we have been able to dissociate which aspects of visual memory are enhanced using a novel recognition memory task in which conjunctions of features (colour, shape, and location) can be independently manipulated. On this task the recogni-

tion rate (measured as d') of synaesthetes was increased (overall) and the false alarm rate was decreased when colour was the unbound feature but not when shape or location was the unbound feature. That is, synaesthetes have a selective advantage for rejecting distractor items when the colours of stimuli are swapped.

Our results are consistent with other findings suggesting that visual memory is enhanced in synaesthesia when colour is a task-relevant feature: for instance, in simple recognition memory for coloured chips (Yaro & Ward, 2007), visual paired associations involving colour and shape (Rothen & Meier, 2010), and when learning and recalling the location of coloured chips in a grid (Yaro & Ward, 2007). Yaro and Ward (2007) speculated that the memory advantage in grapheme-colour synaesthetes may be limited to colour and stimuli that evoke colour (i.e. verbal material). This does not appear to be the case as advantages are also found for certain achromatic abstract visual stimuli such as geometric patterns (e.g. Rothen & Meier, 2010). So the enhancement is neither as broad as episodic memory in general nor as narrow as a colour-specific memory enhancement, but lies some way in between (for a review see Rothen et al., 2012). One hypothesis is that the perceptual differences found in synaesthetes may map on to the distinction between magno- and parvo-cellular systems (Barnett et al., 2008) where the latter is colour-sensitive, and it has been suggested that this may carry into memory processes too (Rothen et al., 2012).

In traditional models of memory, perceptual modules (e.g. for colour recognition) are merely a passive conduit into the episodic memory system (although they are assumed to support phenomena such as repetition priming). As such, differences in colour sensitivity are not considered relevant to episodic memory, except in the trivial case in which not being able to tell colours apart would inevitably lead to worse memory for target and distractor stimuli that differ by colour. We have no reason to believe that our control sample had basic colour vision deficiencies (although we did not test for it) and the vast majority of our participants were female for whom dichromacy would not be expected. On the contrary we suggest that having a more differentiated, or less noisy, colour perception system in synaesthetes affords greater opportunities for episodic learning when colour is a discriminating feature. In this alternative view of memory and perception, the colour system is an integral part of the memory system not a conduit into it. In terms of candidate mechanisms, Lu and Doshier (2009) propose two general mechanisms of perceptual learning: stimulus enhancement (the extent to which neural representations are tuned to particular stimuli) and external noise exclusion (the extent to which competing representations are suppressed). These same mechanisms may also contribute towards declarative memory for perceptual stimuli. For instance, a recent study found that individual differences in short-term colour memory (remembering a colour presented under different lighting conditions) is linked to performance on tests of working memory involving sentences and numbers (Allen, Beilock, & Shevell, 2011).

One unanswered question is whether the finding is limited to synaesthetes or whether we'd find a similar pattern

¹ That is, synaesthetes are more homogeneous as a group on this measure (Levene's $F = 9.06, p = .004$).

if we were to sample from, say, the upper and lower quartile of colour perception abilities (again excluding pathologies in colour vision). Our prediction is that we would be able to replicate the finding in appropriately selected non-synaesthetes. That is synaesthesia may have provided us with a useful way of recruiting from the high end of colour ability, but the findings have potential implications for understanding individual differences that go far beyond synaesthesia.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.cognition.2012.12.012>.

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