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Superior encoding enhances recall in color-graphemic synesthesia

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Abstract. Synesthesia is a phenomenon in which particular stimuli, such as letters or sound, generate a secondary sensory experience in particular individuals. Reports of enhanced memory in synesthetes raise the question of its cognitive and neurological substrates. Enhanced memory in synesthetes could arise from the explicit or implicit use of a synesthetic cue to aid memory, from changes unique to the synesthete brain, or from both, depending on the task. To assess this question, we tested nine color-graphemic synesthetes using standardized neuropsychological measures that should not trigger color-graphemic synesthesia (visuo-spatial tests) and measures that should trigger color-graphemic synesthesia (verbal tasks). We found a synesthetic advantage on both types of tests, primarily in the initial encoding of information. The pattern of results adds to existing evidence of advantages in synesthetic memory, as well as provides novel evidence that synesthetes may have enhanced encoding rather than superior recall. Synesthetes learn more initially, rather than forgetting less over time.

1 Introduction

Synesthesia is a phenomenon in which particular stimuli, such as letters or sound, generate a secondary sensory experience, known as a percept or a concurrent. Interviews with synesthetes have repeatedly shown that synesthetes believe they have better memory for names, places, or faces than do their non-synesthetic counterparts. Yaro and Ward (2007) found that synesthetes were more likely than non-synesthetes to report superior memory, which other papers reported anecdotally (Mills et al 2002; Paulesu et al 1995; Smilek et al 2002). Experimental studies have focused specifically on purported synesthetic benefits in memory (Mills et al 2006; Rothen and Meier 2009, 2010a; Yaro and Ward 2007) and on the impact of synesthesia on general cognition (Mann et al 2009; Simner et al 2009). Although most papers found a significant difference between synesthete performance and non-synesthete performance, the pattern of results and the authors' interpretations varied.

A case study of synesthete MLS found that she performed better than control participants on several memory tests that triggered her color-graphemic synesthesia, such as remembering written names, but not on tests that did not draw on her synesthesia (Mills et al 2006). MLS reported that she could use her synesthetic percept to help her recall stimuli. Mills et al suggested that MLS's superior performance was the result of dual coding, meaning that a stimulus was remembered both as a verbal construct (a word) and a visual construct (a color). With a group of 16 lexical-color synesthetes who experienced color for both written and heard words, Yaro and Ward (2007) likewise reported that synesthetes tended to do better than the control group on tests that triggered their synesthetic percepts, as well as on tests of color recognition memory. These investigators rejected dual coding, which they called "overt back translation", in their explanation of these results. When asked about their strategies, most synesthetes did not report using their synesthetic colors to aid recollection. In addition, overt back-translation would not directly explain synesthete superiority on tests of color recognition and memory. Yaro and Ward suggested that synesthetes have an enhanced ability to retain color information. Enhanced color recall would explain improved memory both for stimuli that cause synesthetic percepts and for the colors themselves. Under this model, synesthesia could partially arise from unusually stable links between different sensory experiences, such as color and words, which persist implicitly in perceptual memory and give rise to synesthesia.

Other investigators have found different patterns of memory advantage in synesthesia. Rothen and Meier (2009) presented a grapheme matrix to 13 color-graphemic synesthetes and 13 control participants and found no group differences. In a later study, Rothen and Meier (2010a) used the Wechsler Memory Scale—R to test another 44 color-graphemic synesthetes and 44 control participants. They found significantly better performance by the synesthetes on both the verbal and spatial index scores, but noted that their performance was not extraordinary (ie more than one standard deviation above the norm) on most of these tests. Rothen and Meier (2010a) suggested that synesthesia conveyed a synesthetic domain-local benefit in memory retrieval, a so-called 'island of ability'. Much like Yaro and Ward, they rejected specific color-pairing information as the cause of improvement. Instead, they attributed improved performance to greater experience in the synesthetic sensory domain, as well as to a supposed synesthetic proclivity for visual imagery. In another example of domain-specific advantages, Simner et al (2009) demonstrated that visuo-spatial synesthetes, who sense ordered sequences (such as time) as a spatial construct, performed better on tests that draw on episodic memory or visuo-spatial skills. Several synesthetes reported consciously employing their synesthetic percepts to remember significant events, but did not report a similar strategy during the visuo-spatial tasks. Simner and colleagues suggested that either some cognitive process that generated superior visuo-spatial abilities in turn led to synesthesia or that the synesthesia itself caused the better performance. This is similar to Yaro and Ward's surmise that implicit learned associations between color and verbal stimuli could give rise to synesthesia.

These experimental papers displayed a pattern of superior recall, in which synesthetes tended to exhibit decreased forgetting of stimuli over a short (15–20 min) or long (1 h or more) duration, rather than faster learning during initial presentation. Yaro and Ward (2007) proposed that this particular learning pattern signaled improved storage and not improved encoding, perhaps due to the synesthetes' theorized ability to better retain color. Still, there is no consensus about the synesthetic reliance on a cue for improved memory. Mills and colleagues (2002, 2006), Rothen and Meier (2010a), and Simner et al (2009), all implied that a cue could be factored into improved memory, either as a paired cue during encoding or as an error-checking mechanism during retrieval. According to this idea, additional sensory retrieval cues provided by synesthesia are the primary source of improved declarative memory. In the present study, we refer to this as the cue-induced encoding/retrieval (CIE/R) hypothesis, with no specification of whether the cue is used consciously (overtly) or unconsciously (covertly), or whether it is used at the initial learning stage, the recall stage, or both. The synesthete should show selective improvement on tasks that trigger synesthesia and no improvement on tasks that do not.

Another hypothesis is that superior declarative memory in the synesthete results primarily from a difference in brain structure between synesthetes and non-synesthetes. Increased white matter connectivity revealed with diffusion tensor imaging (DTI) indicated a potential difference in brain structure in 18 synesthetic and 18 controls (Rouw and Scholte 2007). A study of 18 synesthetes and 18 control participants used voxel-based morphometry to demonstrate that, on average, synesthetes had increased grey matter volume in the left intraparietal sulcus and right fusiform gyrus (Weiss and Fink 2009). These studies imply that other differences could exist between the brains of synesthetes and non-synesthetes that could coincidentally give rise to variations in non-synesthetic behavior. By this account, better declarative memory is independent of the synesthetic response and dependent on the unique structure of the synesthetic brain. We refer to this as the alternative structural organization (ASO) hypothesis.

These two hypotheses lead to different behavioral predictions. If the CIE/R hypothesis is correct, synesthetes would perform better only on tasks that included synesthesia-inducing stimuli. For example, a color-graphemic synesthete would perform well on verbally mediated tasks that triggered his/her synesthesia. By contrast, the same synesthete would perform at a level equivalent to control participants when administered a non-triggering spatial span test. If the ASO hypothesis is correct, synesthetes should perform better on a variety of memory tasks, regardless of whether those tasks invoked a synesthetic response. It should be noted that these hypotheses are not in direct conflict with one another. Synesthetes may tend to use covert or overt cued recall for stimuli that trigger their synesthesia, resulting in better performance. Use of such recall may be supported by observed brain differences in areas such as the fusiform cortex, which may also support enhanced performance on tasks that do not trigger recall (Paulesu et al 1995; Weiss and Fink 2009). As the fusiform cortex is already thought to play a role in semantic memory recall of words, colors, and faces, changes in the fusiform cortex due to synesthesia might positively affect memory function (Martin and Chao 2001).

2 Methods

2.1 *Participants*

We tested nine color-graphemic synesthetes and twenty-three matched control participants. Not all participants received all tests owing to limits of participant availability. All were female and right-handed. Synesthetes ($M = 22.4 \pm 2.7$ years of age) and control participants ($M = 20.7 \pm 2.6$ years of age) were not significantly different in age ($t_{30} = -1.7$, $p = 0.092$). Synesthetes had more years of formal education ($M = 16.1 \pm 2.1$ years of education) than the control group ($M = 14.6 \pm 1.5$ years of education) ($t_{32} = -2.3$, $p < 0.05$). Adding age and education as covariates in the analyses of variance produced no significant main effect for any test or subtest.

To confirm synesthesia, all participants (on visits 1 and 2) completed a modified form of the Test of Genuineness (Baron-Cohen et al 1987), consisting of 150 nouns, verbs, digits, nonsense words, and shapes, by assigning a color to each word. In addition, all potential synesthetes (on visits 1 and 2) used the PANTONE® color system, which assigns numerical values to each color, to select specific hues that matched each letter of the alphabet. Three independent rates evaluated the intra- and inter-test results for consistency among responses. As suggested by Baron-Cohen and colleagues (1987), we set a cut-off of 75% similarity between the first and subsequent testing sessions as a hallmark of synesthetic ability. All synesthetes scored over 85%, whereas control scores ranged between 40% and 60%. We had used these tests across several experiments with consistent results.

During screening, all synesthetic participants reported seeing color for printed words. In addition, many synesthetes reported seeing colors when hearing or thinking about words. As mentioned in Simner (2007), the term color-graphemic is misleading, since many color-graphemic synesthetes also experience color for heard words (color-phonemic). Because the synesthetes in the present study primarily identified themselves as being color-graphemic, however, we use this term to represent them.

2.2 *Procedure*

We administered two categories of memory tests: those that should trigger synesthesia (verbal tests), and those that should not trigger synesthesia (visuo-spatial tests) (table 1). We included standard neuropsychological tests, such as the Rey–Osterrieth Complex Figure. The scoring systems for these tests, such as the Boston Qualitative Scoring System

Table 1. Total number of synesthetes and control participants in each test, as well as whether the test triggers synesthesia.

Neuropsychological test	Verbal or non-verbal	Potentially triggers color-graphemic synesthesia?	Number of synesthetes	Number of control participants
WRMT—Words	verbal	yes	7	8
WMS-III: Paired Verbal Associates subtest	verbal	yes	6	19
WMS-III: Digit Span subtest	verbal	yes	6	20
CVLT-II: California Verbal Learning Test—II	verbal	yes	9	20
WMS-R: Paired Visual Associates subtest	non-verbal	no	4	8
WMS-III: Spatial Span subtest	non-verbal	no	6	20
WRMT—Faces	non-verbal	no	7	8
ROCF	non-verbal	no	7	8

for the Rey–Osterrieth Complex Figure (Stern et al 1999) assess not only long-term memory but also immediate memory, working memory, and planning strategies. These scoring methods provide a more complete profile of how synesthetes and control participants remembered their stimuli than those described by Rothen and Meier (2009, 2010a), Mills and colleagues (2002), and other papers on synesthesia. For analyses, we used raw scores instead of scaled scores, because the control group and synesthetes were matched on age and gender distribution.

2.2.1 *Verbal memory tests.* These are tests of memory that use verbal stimuli that should trigger synesthesia in color-graphemic synesthetes.

Warrington Recognition Memory Test—Words (WRMT) (Warrington 1984). During the initial presentation, the participant rated 50 words as pleasant or unpleasant. After 30 min, participants viewed 25 new words and 25 words from the initial list and were asked if they had seen the words before. We altered the test to increase the difficulty and reduce ceiling effects by changing the test from immediate to long-delay recall (30 min) and from a forced choice to yes–no recognition.

Wechsler Memory Scale—Third Edition (WMS-III): Paired Verbal Associates (Wechsler 1997). The Paired Verbal Associates subtest is a verbal encoding task designed to measure cued immediate and delayed (30 min) recall. Participants heard 8 pairs of words during learning. During recall, participants reported which word was paired with a verbal cue.

Wechsler Memory Scale—Third Edition (WMS-III): Digit Span (Wechsler 1997). The Digit Span subtest measures verbal working memory. In the forward condition, participants repeated a sequence of numbers in the same order as they were presented. In the backward condition, participants repeated a sequence of numbers in the reverse order.

California Verbal Learning Test (CVLT-II) (Delis et al 2000). This is a widely used measure of verbal memory. During training, participants heard and repeated a list of 16 words 5 times. After hearing and reporting a distractor list, the participant immediately recalled words from the first list. After 30 min, the participant again recalled words from the first list without hearing it repeated again.

2.2.2 *Visuo-spatial memory tests.* These tests consist of visual, non-verbal stimuli, specifically faces, lines, shapes, and blocks, that should not trigger synesthesia.

Warrington Recognition Memory Test (WRMT)—Faces (modified) (Warrington 1984). During the initial presentation, the participants rated 50 faces as pleasant or unpleasant. After 30 min, they viewed 50 faces, 25 novel and 25 previously shown, and identified whether they had seen the faces before. The original form of the WRMT employs forced-choice recognition and immediate recall. In order to increase the difficulty of the test and reduce ceiling effects, we changed the recall section to a yes–no recognition task and lengthened the recall duration to 30 min.

Wechsler Memory Scale—Revised (WMS-R) Paired Visual Associates (modified) (Wechsler 1987). Our modified version targets memory for visual stimuli. During training, the participant learned 8 pairs of standard shapes and nonsense shapes. On immediate recall or 30 min delay, the participant recalled the standard shape when presented with only the nonsense shape. The original WMS-R Paired Visual Associates paired a colored square with a nonsense shape. We altered the test, to eliminate potential conflicts between the participant's synesthesia and the colors, by replacing the colored squares with line drawings of common shapes. However, we did not modify the nonsense shapes.

Wechsler Memory Scale—Third Edition (WMS-III): Spatial Span subtest (Wechsler 1997). The Spatial Span subtest measures working memory in the visuo-spatial domain. In the forward span condition, participants tapped blocks in the same order as the presenter. In the backward span condition, participants tapped blocks in the opposite order as the presenter.

Rey–Osterrieth Complex Figure (ROCF) (Rey 1941; Osterrieth 1944). The ROCF is a measure of spatial memory. The participant copied a figure without being told to remember it. Then, the participant drew that figure twice (immediately and after 30 min) without the picture present. We used the Boston Qualitative Scoring System (BQSS) to score the test (Stern et al 1999). The BQSS evaluates several cognitive domains, including memory, planning, and spatial awareness.

3 Results

Synesthetes performed significantly better on three verbal tests, specifically the Warrington Recognition Memory Test—Words, the Paired Verbal Associates subtest of the Wechsler Memory Scale—III, and the California Verbal Learning Test—II, as well as on three subsets of the Rey–Osterrieth Complex Figure.

3.1 *Verbal tests*

Warrington Recognition Memory Test—Words. As displayed in figure 1, there was a significant difference between synesthete performance ($M = 46.5 \pm 2.9$) and control performance ($M = 42.9 \pm 2.2$) ($t_{12} = -2.4$, $p < 0.05$).

Paired Verbal Associates. A 5 (trial) × 2 (group) mixed-model ANOVA was conducted. As shown in figure 2, there was a significant main effect of trial ($F_{1.8,\,42.2} = 38.5$, $p < 0.01$, $\eta = 0.63$), but not group ($F_{1,\,23} = 3.1$, $p = 0.089$), and there was no trial × group interaction ($F_{1.8,\,42.2} = 0.9$, $p = 0.39$). Both groups exhibited better performance with successive recall trials. All synesthetes reached ceiling on trial 3 and trial 4 ($M = 8 \pm 0.0$ for all synesthetes on both trials), while none of the control participants reached ceiling ($M = 6.6 \pm 2.2$ and $M = 7.0 \pm 2.2$, respectively). The synesthetes' reaching ceiling flattened the curve and potentially masked significant differences between the groups on trials 3 and 4. In order to determine if significant results were masked by the synesthetes' reaching ceiling, a one-way ANOVA was conducted on each of the trials. Synesthetes ($M = 5.0 \pm 1.7$) performed significantly better than did the control group ($M = 2.89 \pm 2.2$) on trial 1 ($F_{1,\,24} = 4.5$, $p < 0.05$).

Digit Span. A 2 (forward span versus backward span, 'direction') × 2 (group) mixed-model ANOVA displayed a significant main effect of direction ($F_{1,\,26} = 52$, $p < 0.05$, $\eta = 0.68$), but no main effect of group ($F_{1,\,26} = 1.6$, $p = 0.22$) or direction × group

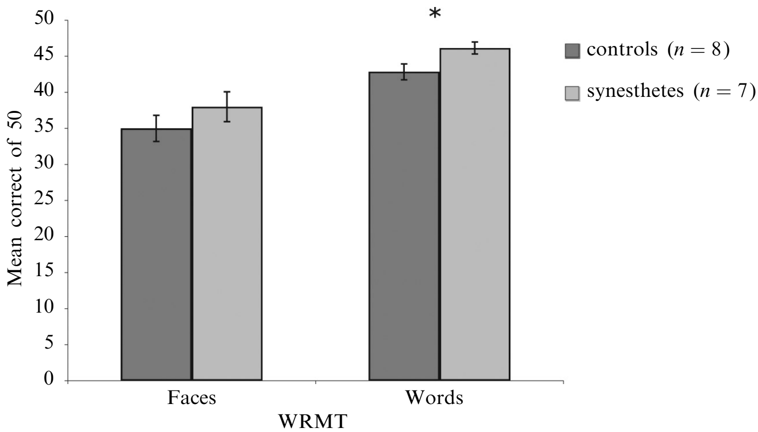

Figure 1. Total scores on the Faces and Words subtests of the Warrington Recognition Memory Test demonstrating that synesthetes performed significantly better than control participants on the Words subtest but not on the Faces subtest. The Words subtest is a verbal task that triggers color-graphemic synesthesia, whereas the Faces subtest is a visuo-spatial task that does not trigger color-graphemic synesthesia. Note: $*p < 0.05$.

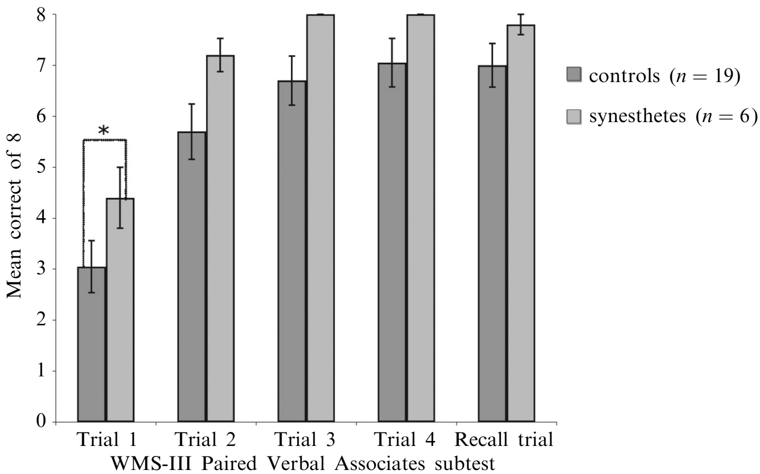

Figure 2. Average scores on the individual presentation trials and the final recall trial of the Paired Verbal Associates subtest of the Wechsler Memory Scale—III (WMS-III) demonstrating a significant difference between control participants and synesthetes on the initial trial. The Paired Verbal Associates subtest is considered a verbal test that should trigger color-graphemic synesthesia. Note: $*p < 0.05$.

($F_{1,26} = 1.5$, $p = 0.23$). The means of the synesthete and control groups were not significantly different on forward span ($M = 12.7 \pm 2.2$ synesthetes; $M = 11.9 \pm 2.2$ controls, $p = 0.46$) or backward span ($M = 10.3 \pm 2.2$ synesthetes; $M = 8.6 \pm 2.4$ controls, $p = 0.13$). Both groups had longer spans forward than backward.

CVLT-II. A 5 (trial) × 2 (group) mixed-model ANOVA performed on the results from the first five trials showed a significant main effect of trial ($F_{3.2,74.2} = 100.1$, $p < 0.05$, $\eta = 0.81$), but not of group ($F_{1,23} = 0.76$, $p = 0.40$), and there was no trial × group interaction ($F_{3.2,74.2} = 0.67$, $p = 0.62$). There was no significant difference between performance of the synesthetes and control participants on any of the first five presentation trials. As shown in figure 3, all participants performed better over repeated trials ($M = 7.3 \pm 1.7$ synesthetes and $M = 7.3 \pm 2.4$ control group on trial 1 versus $M = 14.9 \pm 1.1$ synesthetes and $M = 14 \pm 1.5$ control group on trial 5). Both groups

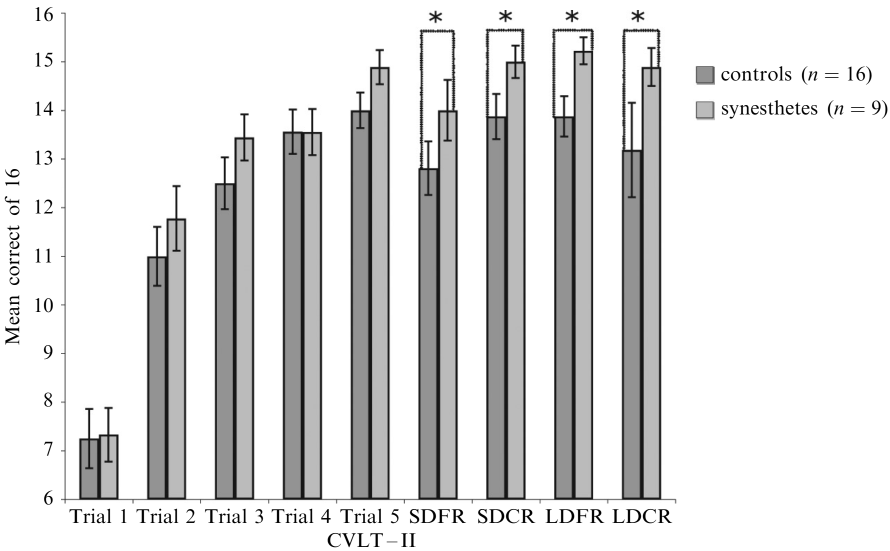

Figure 3. Average scores on the five initial trials and the short and long delay-free and cued recall trials of the California Verbal Learning Test—II (CVLT-II). Synesthetes performed better than control participants on short delay (SD) free recall (FR) and cued recall (CR) as well as on long delay (LD) free recall and cued recall. The CVLT-II was considered a verbal, triggering test. Note: $*p < 0.05$.

improved to the same extent over all five trials. The four recall trials, including short delay-free recall (immediately following distractor list), short delay-cued recall (immediately following free recall), long delay-free recall (30 min), and long delay-cued recall (30 min) were compared using a 4 (trial) × 2 (group) mixed-model ANOVA. The analyses revealed a significant main effect of group ($F_{1,23} = 5.9$, $p < 0.05$, $\eta = 0.33$). Synesthetes performed consistently better on all four recall trials ($M = 14 \pm 1.8$, $M = 15 \pm 1.0$, $M = 15.2 \pm 0.8$, $M = 14.9 \pm 1.2$) than did the control participants ($M = 12.8 \pm 2.2$, $M = 13.9 \pm 1.9$, $M = 13.9 \pm 1.7$, $M = 13.2 \pm 3.9$).

In order to determine whether better recall was correlated with the number of correct answers on the 5th presentation trial, a Pearson correlation coefficient was calculated for trial 5 and all four delayed recall trials. Significant correlations were found between trial 5 and short delay-free recall [$r = 0.74$ (23), $p < 0.001$], trial 5 and short delay-cued recall [$r = 0.07$ (23), $p < 0.001$], and trial 5 and long delay-free recall [$r = 0.69$ (23), $p < 0.001$]. A higher score on the final-presentation trial was associated with a higher score on both of the short-delay recall trials and the 30 min free-recall trial for both groups.

Synesthetes and control participants displayed similar average performance, represented by the percentage of correct responses on trial 5 of the initial presentation trials ($M = 14.9 \pm 1.1$ synesthetes, $M = 14 \pm 1.5$ controls) and on long delay-cued recall ($M = 14.9 \pm 1.2$ synesthetes, $M = 13.2 \pm 3.9$ controls). A 4 (recall trial) × 2 (group) mixed-model ANOVA was performed that demonstrated that after the first recall trial, synesthetes performed better on average ($M = 14 \pm 1.8$) than did control participants ($M = 12.8 \pm 2.2$) ($F_{1,23} = 5.4$, $p < 0.05$, $\eta = 0.190$). In addition, both groups demonstrated a similar significant ($p < 0.01$) improvement in performance when comparing short delay-free recall and short delay-cued recall.

To examine the potential strategies used when remembering items from the list, a 5 (trial) × 2 (group) mixed-model ANOVA was performed on data that display how participants tended to recall items (eg by using serial recall or semantic clustering).

A significant trial effect was observed ($p < 0.05$), but no significant main effect of group or group × trial was observed on any measure, with the exception of recall from the middle on trial 5 ($F_{1,23} = 0.20$, $p < 0.05$). On this trial, synesthetes were significantly more likely to recall information from the middle of the list. These data imply that the two groups generally used a similar overall strategy when remembering the list on the first five presentation trials. This strategy comprised a shift from a serial strategy, which relies primarily on primacy and recency, to a strategy based on semantic clustering. Similarly, a 7 (trial) × 2 (group) ANOVA, based on clustering strategy during recall, showed a significant trial effect ($p < 0.05$) for all measures but recall from recency. This indicated that synesthetes and control participants continued to use the semantic clustering strategy.

3.2 *Visuo-spatial tests*

3.2.1 *Paired Visual Associates.* A 5 (four presentation trials and one recall trial 'trial') × (synesthetes versus control 'group') mixed-model ANOVA was conducted and a significant main effect of trial was exhibited ($F_{1.8,17.5} = 20.6$, $p < 0.01$, $\eta = 0.67$). There was no significant main effect of group ($F_{1,10} = 0.13$, $p = 0.73$) or interaction of trial × group ($F_{1.8,17.5} = 0.8$, $p = 0.47$). Both groups performed significantly better on trial 3 ($M = 8.0 \pm 0.0$ synesthetes; $M = 7.4 \pm 0.9$ controls) and trial 4 ($M = 8 \pm 0$ synesthetes, $M = 7.6 \pm 0.5$ controls) than on trial 1 ($M = 4.5 \pm 1.3$ synesthetes; $M = 5.0 \pm 2.3$ controls). Both groups improved to the same extent over the course of the test and both groups reached ceiling at trial 3.

3.2.2 *Spatial Span.* A 2 (forward versus backward span 'direction') × 2 (group) mixed-model ANOVA was conducted. There was no main effect of group ($F_{1,24} = 0.02$, $p = 0.89$), direction ($F_{1,24} = 0.6$, $p = 0.59$, $\eta = 0.01$), or direction × group interaction ($F_{1,26} = 0.02$, $p = 0.89$). The groups demonstrated similar means on forward span ($M = 8.5 \pm 1.4$ synesthetes; $M = 8.3 \pm 2.0$ controls) and backward span ($M = 8.2 \pm 1.3$ synesthetes; $M = 8.1 \pm 1.9$ controls).

3.2.3 *Warrington Recognition Memory Test—Faces.* A t-test displayed no significant difference between performance of synesthetes ($M = 38 \pm 4.8$) and controls ($M = 35 \pm 5.5$) ($t_{12} = -1.1$, $p = 0.30$).

3.2.4 *Rey – Osterrieth Complex Figure.* In order to determine how participants performed overall, a 3 (trial) × 2 (group) mixed-model ANOVA was conducted for the sum scores on the copy, immediate recall, and long-delay recall conditions. There was a significant main effect for trial ($F_{2,26} = 8.4$, $p < 0.01$, $\eta = 0.39$) and for the trial × group interaction ($F_{2,26} = 3.7$, $p < 0.05$, $\eta = 0.22$). There was no main effect of group ($F_{1,13} = 1.1$, $p = 0.31$). Synesthetes and control participants performed better on the initial copy condition ($M = 56.4 \pm 3.9$ synesthetes; $M = 52.3 \pm 5.3$ controls) than they did on either the immediate recall condition ($M = 50.1 \pm 4.0$ synesthetes; $M = 51.5 \pm 6.6$ controls) or the long-delay recall condition ($M = 51.9 \pm 4.7$ synesthetes; $M = 47 \pm 5.9$ controls) figure 4).

A 3 (trial) × 2 (group) mixed-model ANOVA was conducted for each of the 16 segments of the complex figure. Only those memory subtests that elicited a significant group difference are reported here; specifically, configural accuracy (accuracy for the overall shape of the figure) and cluster accuracy (accuracy for individual clusters of shapes within the figure) (figure 5). For configural accuracy, the main effect of group was significant ($F_{1,13} = 8.5$, $p < 0.05$, $\eta = 0.40$). No significant main effect was observed for trial ($F_{2,26} = 1.4$, $p = 0.26$) or for the trial × group interaction ($F_{2,26} = 0.14$, $p = 0.26$). Synesthetes performed better on the initial copy condition ($M = 3.7 \pm 0.5$) than did control participants ($M = 2.4 \pm 0.9$), ($p < 0.01$), which may account for their significantly better performance on this portion of the initial recall condition ($p < 0.05$).

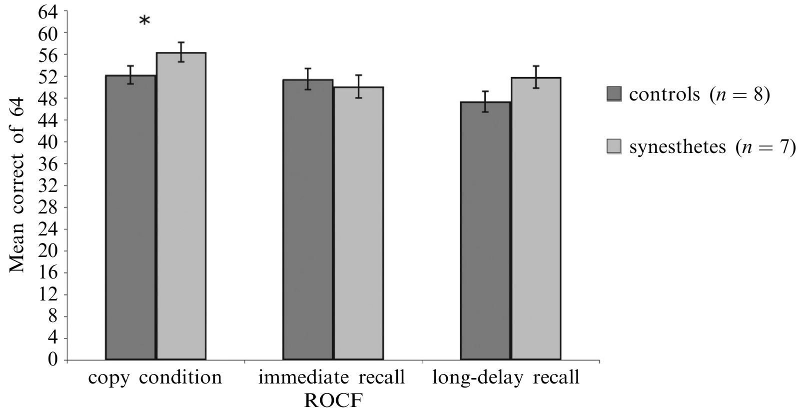

Figure 4. Total scores for each phase of the Rey – Osterrieth Complex Figure (ROCF) demonstrating that synesthetes performed significantly better than control participants on the copy condition. The ROCF is a visuo-spatial, non-triggering task. Note: $* p < 0.05$.

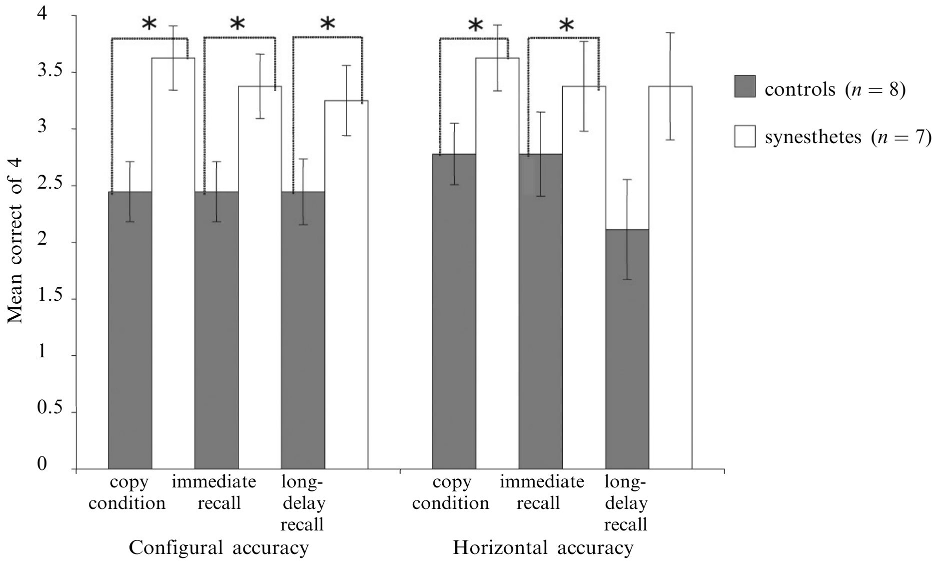

Figure 5. Average scores on configural accuracy and cluster accuracy for the Rey – Osterrieth Complex Figure (ROCF). Synesthetes performed better than control participants on configural accuracy, which measures the accuracy for the overall figure, for all three conditions of the ROCF. On cluster accuracy, which measures the accuracy of individual clusters of shapes within the figures, synesthetes performed better than control participants on the copy and long-delay recall conditions. Note: $* p < 0.05$.

For cluster accuracy, the interaction of group × trial was significant ($F_{2,26} = 4.5$, $p < 0.05$, $\eta = 0.26$). There was no significant main effect of trial ($F_{1,13} = 3.2$, $p = 0.057$) or group ($F_{2,26} = 2.6$, $p = 0.13$). On the copy condition ($M = 3.3 \pm 0.5$ synesthetes; $M = 2.3 \pm 1.2$ controls; $p < 0.05$) and long-delay recall condition ($M = 2.7 \pm 0.5$ synesthetes; $M = 1.7 \pm 0.89$ controls; $p < 0.05$), synesthetes performed better than did control participants.

4 Discussion

The synesthetes demonstrated significant memory advantages in domains triggered by synesthesia, specifically spoken words and written words, while generally performing at the level of control participants for non-triggering stimuli. In this respect, the results are similar to those of Rothen and Meier (2010a) and Simner et al (2009). In contrast with those other studies, however, improvement in synesthete memory was seen both early and later in the memory process. Our findings mainly support the cue-induced encoding/retrieval hypothesis in that most of the significant results were elicited by the tests that triggered synesthesia, specifically the Warrington Recognition Memory Test—Words, Paired Verbal Associates, and the California Verbal Learning Test—II. The improved recall on the Rey–Osterrieth Complex Figure, which should not have triggered synesthesia, suggests that there was another mechanism at work for non-synesthetic domains. Potentially, the differences in performance on the Rey–Osterrieth Complex Figure are due to parietal-lobe changes known to be a part of synesthesia, supporting the Alternative Structural Organization hypothesis (Esterman et al 2006; Weiss and Fink 2009).

The data suggest that synesthetes have an enhanced encoding mechanism that allows them to learn more information earlier, rather than forget less information later. The visibly improved encoding and its corresponding better performance persisted across both verbal and visual domains and was significant for several tests. Small differences in performance between synesthetes and control participants were seen as early as the first trial on the CVLT-II, though the group differences were not significant until the first short-delay recall condition. Better performance by synesthetes on the Paired Verbal Associates subtest also occurred only in the earliest two trials of the test. The biggest difference between the control group and synesthetes on the Rey–Osterrieth Complex Figure was on the copy condition, which served as the encoding trial.

There was a group difference in performance on the written portion of the modified Warrington Recognition Memory Test. Unlike in other tests of declarative memory, exposure to stimuli occurred as part of an implicit learning, judgment-style task (pleasant or unpleasant). If this were a conscious learning task, the synesthetes might have devised a strategy that incorporated their synesthetic percepts during encoding or recall. In the presentation task on the WRMT, there was no benefit conferred by using synesthesia to making arbitrary judgments of pleasantness or unpleasantness. This implicit task is unlikely to trigger a conscious, cue-binding mechanism of recall, given the short duration of stimulus presentation and the lack of explicit instructions to remember the target. Instead, an implicit pairing mechanism, perhaps covert dual-coding as suggested by Yaro and Ward (2007), or some other form of enhanced encoding might be involved. Therefore, we consider the synesthete performance on this test to support the cue-induced encoding/retrieval hypothesis. Since there is no objective measure of encoding on the WRMT, we cannot determine if enhanced encoding was relevant to improved synesthete performance. Use of a serially presented set of verbal and facial stimuli that includes an immediate recall condition, such as a visual version of the CVLT-II, would allow assessment of this possibility.

The Paired Verbal Associates test scores suggested faster learning. There was a significant synesthete advantage as early as the first trial. When synesthetes reached ceiling at trial 3, it was no longer possible to tell whether the initial benefits from the first trial carried through the remainder of the test, since the synesthetes were no longer improving. The CVLT-II data implied that an advantage might persist on a similar test of increased difficulty. Rothen and Meier (2010a) indicated that synesthetes performed better on both the immediate and delayed-recall condition of the Paired Verbal Associates subtest of the WMS-R, though it is not clear if the results represented better performance on average or better performance on selected trials.

The better recall of the synesthetes than the control group on the CVT-II does not perfectly support cue-induced encoding/retrieval hypothesis. Synesthetes continually performed better than did the control group across the test, as anticipated by this hypothesis.

If the synesthetes had relied primarily on their synesthetic cues to aid them with recall on the CVLT-II, however, they should have eschewed semantic clustering in favor of a predictable, familiar implicit or explicit cue. Instead, synesthetes and control participants used a similar strategy, yet synesthetes still performed better during recall, indicating that another mechanism besides superior planning or a synesthetic cue was at work. This raises the question whether synesthetes, when confronted with a choice, tend to select conventional methods of verbal organization (in this case, semantic clustering) over individualized strategies driven primarily by synesthetic perceptions.

On several subtests of the Complex Figure, a non-verbal, visuo-spatial test, synesthetes displayed significantly better performance on the long-delay recall condition than did the control participants. For both synesthetes and the control group, performance on the copy condition predicted performance on the long-delay recall condition, with higher scores on the copy condition usually resulting in higher scores on the long-delay recall condition. On average, all participants suffered a similar decrement in performance across the three trials. These results suggest that it is more likely that participants with higher long-delay recall scores had a better grasp of the figure initially, rather than displayed better memory. Synesthetes did not remember elements of the Complex Figure better than control participants, but they learned the information more accurately.

It is important to note that several researchers have shown that individuals with synesthesia involving vision tend to have better visuo-spatial skills than do non-synesthetes. Simner and colleagues (2009) and Price (2009) reported that visuo-spatial synesthetes performed better than control participants on tests of visual memory and visual manipulation. Price (2009) also showed that synesthetes tended to rate themselves as using more vivid visual imagery than did non-synesthetes. Rothen and Meier (2010b) noted that there was a higher prevalence of color-graphemic synesthesia in art students than in a general, university-involved population. These papers suggest that superior visuo-spatial ability, rather than superior encoding, could account for the better performance of color-graphemic synesthetes on the copy condition of the Complex Figure. Although Price (2009) and Simner and colleagues (2009) spoke about improved visual skills in visuo-spatial synesthetes, it is reasonable to suppose that color-graphemic synesthetes in general could also possess similar aptitude for visuo-spatial tasks, or that at least some of the synesthetes had a form of visuo-spatial synesthesia, since some made allusions to their personal spatially based calendars. That Mills and colleagues (2002) failed to see a significant difference in performance on the Complex Figure could be due either to individual differences or use of a scoring system that did not assess qualitative differences in performance. Simner and colleagues suggested that motivation was not likely to be a factor in improved performance on visuo-spatial tasks, relative to verbal tasks. We agree with this comment due to the overall enthusiasm among participants for all tests and not just those tests that involved visual components.

If superior encoding is responsible for most of the differences observed, why didn't synesthetes perform better on all verbal tests? It is possible that the test stimuli must be of sufficient complexity or duration in order to trigger a cue. This could explain why single digits presented aurally for only a single trial (Digit Span) did not elicit this effect, whereas words presented aurally for multiple trials did (CVLT-II). Rothen and Meier (2010a) offered a similar explanation for non-significant synesthetic performance on Digit Span. Unlike the synesthetes in Rothen and Meier's study (2010a), the synesthetes in the present study did not perform better than the control group on the Visual Paired Associates subtest of the WMS-R. Presumably, our removing the color information made the test less likely to involve synesthesia, lessening any cued response. It is also possible that superior encoding is tied to participants' use of clustering as a problem-solving technique, as in the CVLT-II and Complex Figure. Use of clustering to encode information is associated with improved memory (Savage et al 2001). There may be an interaction between the processes that underlie clustering and those that result in synesthesia.

The present findings provide new contributions to the portrait of synesthetic memory. Our results primarily support the cue-induced encoding/retrieval hypothesis, but indicate that it is not sufficient to explain all results. Specifically, they demonstrate that synesthetes exhibit improved memory in multiple domains, but that the memory improvement is likely a result of enhanced encoding rather than of enhanced recall. In order to explore the idea of improved encoding, researchers should shift their testing procedures to include more frequent, shorter presentations of information, followed by both immediate recall and long-delay recall. Future studies should employ scoring methods that analyze not only the end score but also intermediate steps of encoding and immediate recall, as well as performance measures such as planning strategy. If superior encoding, rather than decreased forgetting, is the cause for better memory performance in synesthesia, scores will show evidence of this earlier, rather than later, in testing. A focus on encoding rather than, or in addition to, recall will bring us closer to understanding memory in individuals with synesthesia.

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