CHAPTER 35

SYNESTHESIA AND MEMORY

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Introduction

Synesthesia provides for a richer world of experience than normal. Thus, synesthesia may lead to additional retrieval cues and, as a consequence, to an advantage in memory tasks. Evidence in favor of this hypothesis originally came from single-case studies. A case of a synesthete with particularly extraordinary memory ability was Shereshevsky (S), a Russian journalist and mnemonist, described by Luria (1968). S had multiple synesthesias, a very detailed memory for real-life events, and in experimental memory tasks he was able to encode complex materials within a short period of time and recall them accurately even after several years. One of the questions that arose from observations like these was whether synesthesia causes an extra-ordinary memory in general—or simply an advantage for the retrieval from memory. The latter advantage has been suggested repeatedly in the literature, as well as by synesthetes themselves (cf. Cytowic 1993, 2002; Rothen and Meier 2010; Yaro and Ward 2007). However, as self-reports are disputable, controlled experiments are required to resolve this question. Several group studies have addressed this issue. Some have indeed found a performance benefit, at least for some memory tests (e.g., Gross et al. 2011; Radvansky, Gibson, and McNerney 2011; Rothen and Meier 2010; Yaro and Ward 2007). However the memory advantage was not as pronounced as would have been expected from single-case studies. Moreover, a performance advantage for synesthetes could not be confirmed for the digit matrix task in which single cases demonstrated extra-ordinary abilities (see later; Rothen and Meier 2010; Yaro and Ward 2007).

Thus, one major question is to find out under what particular circumstances synesthetes might show a memory performance advantage. Another question is what exactly causes the potential memory advantage. Theoretically, it may be that synesthesia leads to a richer world of experiences and thus to additional retrieval cues in general (cf. Rothen, Meier, and Ward 2012). Accordingly, a general advantage would be expected across a large variety of materials and memory tests. However, it is also possible that the performance benefit for synesthetes is more specific and directly related to inducers, that is, to those materials which trigger the synesthesia (e.g., graphemes for grapheme-color synesthetes). This explanation is related to a dual-coding theory of cognition (cf. Paivio 1969). According to this theory the ability to encode a stimulus in two different ways increases the chance of remembering it compared to a stimulus that was only coded one way. Thus, in synesthesia, the additional memory code triggered by the inducer (i.e., the synesthetic concurrent, e.g., color) would result in a stronger representation and accordingly to a performance advantage compared to non-synesthetes. A third possibility is that the memory advantage of synesthetes is domain-specific. According to this account, the benefit is not restricted to the inducer, but extends to the concurrent (e.g., grapheme-color synesthetes would not only show a performance benefit for graphemes, but also for colors). This theoretical position is compatible with the observation that implicit associations also exist from the concurrent to the inducer (cf. Brugger et al. 2004; Cohen Kadosh et al. 2005; Meier and Rothen 2007; Rothen et al. 2010). Although at the level of conscious experience, the occurrence is typically unidirectional (i.e., a grapheme triggers a color experience, but a color does not trigger a grapheme experience).

In this chapter, we will present a review of the available empirical findings, case reports, and groups studies. The focus is mainly on grapheme-color synesthesia because most of the studies have addressed this form of synesthesia. Table 35.1 provides an overview of these studies and their main findings. We will evaluate the findings according to the three explanations just outlined, that is, whether synesthesia provides for a general, an inducer-specific, or a domain-specific advantage. The review is complemented with an integration of these findings with links to the neural basis of synesthesia and memory.

Memory in Grapheme Color Synesthesia

Case studies

Luria (1968) documented the extraordinary memory of S across a period of almost 30 years, beginning in the early 1930s. It all began when the editor of the newspaper for which S worked as a journalist noted with surprise that S never took any notes, but nevertheless remembered all kinds of information with astonishing accuracy. He sent him to Luria to have his memory investigated. Luria conducted a number of experiments in which S demonstrated his enormous capacity to remember. In one of the tasks he was asked to learn a matrix which consisted of 50 digits, arranged in rows and columns. S needed about 3 minutes for study, and after that he was able to recall the numbers in succession. He was also able to recall a particular column, even in reverse order, or to "read off" the numbers which formed the diagonals. Moreover, he was able to accurately recall such matrices even years later. It turned out that synesthesia was the key to S's extraordinary memory. For digits and letters he experienced colors, movements, and/or

Table 35.1 Overview of studies on memory in synesthesia ordered by support for an inducer-specific, domain-specific (inducer and concurrent) and/or more general advantage

Study type	Author	N	Inducer	Domain	General	Memory test
Case studies						
	Luria (1968)	S	+	+	+	Digit Recall
	Baron-Cohen et al. (2007)	DT	+	nt	nt	Digit Recall
	Smilek et al. (2001)	C	+	nt	nt	Digit Recall
	Mills et al. (2006)	MLS	+	nt	nt	Name Recall, BVRT, RAVLT, RCFT
	Brang and Ramachandran (2010)	JS	nt	nt	+	Hidden Objects, Change Detection
Group studies						
	Yaro and Ward (2007)	16	+/–	+	–	Digit Recall, RAVLT, RCFT, Color Recognition
	Rothen and Meier (2009)	13	–	nt	nt	Digit Recall
	Rothen and Meier (2010)	44	+	+	+	Wechsler Memory Scale (WMS)
	Gross et al. (2011)	≤ 9	+	+	+	WMS, RCFT, CVLT, Recognition Memory
	Radvansky, Gibson, and McNerney (2011)	10	+	nt	nt	Wordlist Recall
	Meier and Rothen (2007)	13	+	nt	nt	Synesthetic Conditioning Task
	Rothen et al. (2010)	36	+	+	nt	Synesthetic Conditioning Task & TMS
	Simner, Mayo, and Spiller (2009)	≤ 10	+	+	nt	Event Memory, Spatial Abilities

+ = support, nt = not tested, – no support. Abbreviations of memory tasks see text.

forms (e.g., "3 is a pointed segment which rotates"; Luria 1968, 26), words elicited "puffs of steam" and splashes, tones triggered colors, sounds triggered tastes, and visual and auditory stimuli also elicited sensations of taste and touch. Luria suggested that these synesthetic experiences created "a background for each recollection, furnishing him with additional "extra" information that would guarantee accurate recall" (Luria 1968, 28). Although the overall characterization of the case of S would seem to support the hypothesis of a general memory advantage, the presence of the various kinds of synesthesia may also indicate that his extraordinary memory was directly related, and therefore limited, to the different domains of his synesthesia. Moreover, S refined his already extraordinary memory ability with mnemonics such as the method of loci and visual imagery which may have been a further and distinguishable source of his extraordinary memory. However, his pronounced use of imagery combined with his synesthetic experiences resulted not only in an excellent memory, it also made it difficult for him to think clearly or to read, because images "kept rising to the surface in his mind" (Luria 1968, 113). Luria characterized him as a dreamer who had difficulties distinguishing between his internally generated thoughts and images, and external reality.

More recently, it has been suggested that S may have suffered from autism which together with his synesthesia may have been the basis for his exceptional memory (Baron-Cohen et al. 2007; Bor, Billington, and Baron-Cohen 2007). Baron-Cohen et al. (2007) presented a similar case, Daniel Tammet (DT), at that time a 26-year-old language genius who was diagnosed as having Asperger's syndrome. Similar to S, DT came to the attention of the researchers because of his extraordinary memory. He was European champion for reciting Pi to over 22,000 decimal places from memory in 2004, and in addition, he published a book in which he described his synesthesia (Tammet 2006). For him, each integer up to 10,000 had its own unique shape, color, texture and feel, and as a consequence, a list of numbers created the experience of a complex landscape. He could intuitively "see" results of calculations in the synesthetic landscape without using conscious mental effort and he was able to "sense" whether a number was a prime or a composite. When his memory was tested in the laboratory (Baron-Cohen et al. 2007), he showed a digit span of 11.5 compared to 6.5 in controls. However, in a face recognition test with a retention interval of about an hour his accuracy was only slightly above chance. Baron-Cohen et al. (2007) concluded that his number memory was superior while his face memory was impaired. Thus, this study provides evidence for a selective memory advantage which seems to be restricted to the realm of the inducer.

However, it is important to note that the presence of Asperger's syndrome or a similar mental condition is not a precondition for extraordinary memory in synesthesia. For example, (Smilek et al. 2002) reported the case of an inconspicuous student (C). After a classroom demonstration on the limits of human memory in which students were presented with four lists of nine digits, she baffled the instructor by recalling each of the lists almost perfectly. In more formal testing, C was tested with three matrices of 50 digits, similar to those used by Luria (1968). One matrix consisted of black digits, another of digits colored congruently with C's synesthetic colors, and a third of digits incongruent with her synesthetic colors. When tested immediately after learning, C showed excellent performance for the black and the congruent matrix. However, her recall for the incongruent matrix was very poor. When tested again after 48 hours with the black matrix, there was no decline in performance. In the control group there was no performance difference between the black, the congruent, and the incongruent matrices and the control group showed a significant decrease when tested again after 48 hours. Smilek et al. (2002) suggested that synesthetic colors provided additional memory cues and therefore played an essential role in C's memory abilities. While these results clearly indicate a memory advantage for the materials that triggered the synesthesia (i.e., digits), it is not clear whether C would have shown a more general memory advantage if she had been tested with different materials.

Similar findings were reported from Mills et al. (2006). They tested the case of a 48-year-old language professor, MLS, who reported that synesthesia helped her to remember names. In one experiment, MLS and two different control groups (one consisting of language professors, the other of visual art professors) were presented with a list of 30 fictitious first and last names followed by a free recall test. Three successive study–test cycles were administered. From the second cycle on, the results showed the expected benefit for MLS which persisted through to a second session 6 months later. In another experiment, MLS was given three standardized tests, two visual tests, the Benton Visual Retention Test (BVRT-R) and the Rey Complex Figure Test (RCFT), and one verbal test, the Rey Auditory Verbal Learning Test (RAVLT). The BVRT consists of ten stimulus cards which contain geometrical shapes. Each is presented for 10 s and must be recalled immediately by drawing the figure from memory. The RCFT consists of the study of a single complex figure with an immediate copy trial and a delayed free recall trial. The RAVLT consists of the presentation of a 15-word list with an immediate recall. This study-test cycle is repeated five times. Then a second 15-word list is presented for immediate recall. After 20 minutes a delayed recall trial of the first list is administered.

Compared to age- and education-matched norm scores, MLS performed numerically, but not statistically higher in the BVRT-R. A similar result was found for the delayed recall of the RCFT. In contrast, MLS showed a clear advantage on the RAVLT. MLS's performance was already close to ceiling after the third study-test cycle. These results again support the notion that synesthesia gives rise to a memory advantage that is specific to the particular inducer. That is, MLS was able to use her synesthesia to remember verbal materials, but she did not show a general memory performance benefit.

A somewhat different result was found in a case study by Brang and Ramachandran (2010). They tested the case of a 25-year-old university student (JS) who experienced (explicit) bidirectional grapheme-color synesthesia. That is, for him graphemes elicited colors and in addition, he also experienced that colors elicited the corresponding graphemes. Moreover, he reported that he would retain a vivid mental picture of even complex scenes for a relatively long period. Brang and Ramachandran (2010) tested this supposed eidetic memory with a hidden object test and a change detection task. In the hidden objects test, JS and a control group were shown three complex visual scenes which contained several target items. Each scene was presented for 30 s and then replaced by a white sheet. A list of target items was read to the participants with the instruction to mark the previous location of each item on the white sheet. In the change detection task, pairs of complex visual images were presented in succession with small changes between the two images. The task was to spot the difference. In both tasks, JS outperformed all participants of the control group, a result that was replicated 6 months later. Importantly, JS did not experience colors for the displays and thus, these results would indicate that, at least for some synesthetes the memory advantage goes beyond the domain of the synesthesia. However, one could also argue that this result is rather due to enhanced imagery in synesthesia—a feature that was also evident in the case of S and is supported by self-report studies on the vividness of imagery in synesthesia (cf. Barnett and Newell 2008; Price 2009).

Altogether the single-case studies illustrate the large individual differences that occur within synesthesia. Some of the cases demonstrated exceptional memory performance and some of them showed a more moderate performance advantage. Unfortunately, testing was restricted to the realm of the inducer of the synesthesia, that is, to verbal and/or numerical materials in most of the cases and thus it seems that the advantage was inducer-specific. Only the results from JS who showed enhanced retention of complex scenes with materials that did not elicit synesthesia can challenge this conclusion (Brang and Ramachandran 2010). Similarly to S, as described by Luria, JS also showed very vivid imagery and it is an open question how imagery may contribute to the memory advantage in synesthesia. Moreover, from the single-case studies it is not clear whether a memory advantage is specific to some individuals or whether it is a fundamental feature of synesthesia, that is, one cannot make generalizations about the memory benefit (see Rothen and Meier 2009). Several group studies have been conducted to test the generality, the magnitude, and the extent of the potential memory benefit in synesthetes. These are reviewed in the next section.

Group studies

Yaro and Ward (2007) recruited a sample of 46 grapheme-color synesthetes and asked them to rate their memory ability. Overall, they reported better than average memory and more frequent use of visual strategies to aid memory. In a second experiment, objective memory performance was tested in a subgroup of 16 synesthetes. As in the study by Mills et al. (2006), the RAVLT and the RCFT were used. In addition, digit matrices with 27 numbers were constructed and presented either in a 3×9 or in a 9×3 array. The matrices were composed individually for each synesthete such that the digits were printed in colors that were either congruent or incongruent with their synesthetic experiences. In addition, a third matrix of colored squares was used in order to test whether synesthetes may have superior memory for color. Moreover, to test whether synesthetes may have an advantage in processing color information, the Farnsworth–Munsell Color Perception test was used in its original and a modified form. In the original form four trays of colored caps must be sorted to form a regular color series transforming from one hue to another (e.g., from red to yellow). In the modified form five color targets were selected from each of the trays and each was presented for 5 s with the instruction to memorize the specific shade of color. Subsequently, these color targets were presented again, together with two similar caps with a slightly different hue and participants had to select the target color.

The results showed a significant performance advantage for the RAVLT (i.e., memory for auditorily presented words), but not for the RCFT (i.e., memory for a complex visual figure), thus replicating the findings of Mills et al. (2006) in a group study. In the digit matrix recall task, Yaro and Ward (2007) found neither a memory advantage for synesthetes nor a differential effect for the congruent versus incongruent matrices. However, for the color matrix task, they found an advantage for the synesthetes in the delayed recall test, suggesting a performance benefit in the domain of the concurrent. A similar result was found for the Farnsworth–Munsell Color Perception tests. Synesthetes outperformed the controls, both in the color perception test and in the color recognition memory test. Therefore, this study provides evidence that synesthetes may have a performance advantage not only for inducers that trigger synesthesia, but also for concurrents, or, even more generally, for the modality in which the concurrents are elicited (i.e., color in general for grapheme-color synesthetes, not only synesthetic colors). Yaro and Ward (2007) concluded that the dual-coding theory cannot account for these results.

A somewhat surprising finding from the study of Yaro and Ward (2007) was the failure to replicate the performance benefit of synesthetes in the digit matrix recall task and the failure to replicate the effect of (in)congruency on memory performance. However, Rothen and Meier (2009) found a similar pattern of results when they compared a group of 13 grapheme-color synesthetes and a control group. Participants were tested with two matrices, one consisting of 50 black digits and one consisting of 50 incongruently colored digits (i.e., colored in a way that did not match their synesthetic color). The latter matrix was composed individually for each synesthete such that the digits were incongruent with each synesthete's own synesthetic concurrents. Memory was tested immediately after learning, after a delay of 30 minutes, and after a delay of 2 to 3 weeks. The results showed no performance benefit for the group of synesthetes compared to the controls, either in immediate or in delayed recall. In addition, there was no disadvantage for memorizing the matrix with incongruently colored digits compared to the black digits. The results suggest that synesthesia per se may not lead to a memory performance advantage, at least not when tested with that particular method.

In a further study, Rothen and Meier (2010) used a standardized memory test, the Wechsler Memory Scale (WMS-R). The specific research question was whether synesthesia would lead to extra-ordinary memory—which was defined as a score of more than one standard deviation above the norm. This was based on the consideration that about two-thirds (i.e., 68.2%) of the observations lay within one standard deviation (SD) above/below the mean and thus only about 16% of the normal population have scores higher than one SD above the mean, that is "extra-ordinary" memory. The WMS-R consists of several subtests: *Digit Span Forward* involves the presentation and immediate recall of a digit-string of increasing length in forward order. *Digit Span Backward* involves the presentation and immediate recall of a digit-string of increasing length in backward order. In *Visual Memory Span Forward*, the experimenter produces sequences of increasing length by touching little blocks which are positioned on a grid. After each sequence, the participant has to reproduce the sequences in forward order. In *Visual Memory Span Backward*, the same procedure is administered but the participant has to reproduce the sequence in backward order. *Figural Memory* examines the ability to remember complex geometrical figures and to recognize them amongst others in an immediate recognition test. *Logical Memory* examines the ability to recall the ideas from two short stories which are presented orally. It is tested immediately and again after a delay. *Visual Paired Associate Learning* involves making a total of six associations between a specific color and a meaningless line drawing. Cued recall of the color is tested after each presentation of the six color-drawing pairs and again after a delay. *Verbal Paired Associate Learning* consists of the oral presentation of six word pairs. Cued recall of the second word is tested when probed with the first one after each presentation of the six pairs and after a delay. *Visual Reproduction* consists of the presentation of geometrical shapes and the immediate and delayed pencil and paper reproduction. Between the *immediate* and the *delayed recall* of *Logical Memory*, *Visual Paired Associate Learning*, *Verbal Paired Associate Learning*, and *Visual Reproduction*, there was a filled retention interval of about 30 minutes.

As this study used a fairly large sample size (i.e., 44 grapheme-color synesthetes), the results are presented in Figure 35.1. Individual test scores were standardized using the corresponding normed reference data. While there was no advantage in the short-term memory tasks, there was a consistent advantage for both verbal and visual memory subtests (within one standard deviation above the norm mean, depicted in green color in Figure 35.1). However, only for immediate visual paired associate learning was this advantage beyond one standard deviation, that is, in an "extraordinary" range (depicted in red color in Figure 35.1). When additional indices for visual and for verbal memory subtests were calculated according to the WMS manual, the synesthetes showed a particular benefit for visual over the verbal memory index. Thus, this study also supports the argument that the memory advantage is not restricted to the inducers. Rather, it seems that "synesthetes [also] profit from the experiences in the domain of the synesthetic concurrent, that is, the visual modality for grapheme-color synesthesia" (Rothen and Meier 2010, 262). As mentioned earlier, this advantage in the visual domain might be related to the enhanced imagery abilities typically reported by synesthetes and, in general, the greater reliance on visual strategies for information processing (cf. Barnett and Newell 2008; Yaro and Ward 2007).

Gross et al. (2011) followed up on the question as to whether the memory advantage of synesthetes is specific to verbal tasks or whether it might extend to visuo-spatial tests. They recruited a total of nine synesthetes who were notably younger on average than the group tested by Rothen and Meier (2010). In the short-term memory test of the WMS (i.e., Digit Span and Visual Span) they found no performance advantage for the synesthetes. In the verbal paired associates WMS subtest they found an advantage for synesthetes, at least for the first trial (on later trials performance was at ceiling). Thus, these results replicate the findings by Rothen and Meier (2010). In order to avoid the presence of color, they devised a modified version of the visual paired associate WMS subtest. Rather than using associations between colors and meaningless line drawings as learning materials, the associations consisted of common shapes and meaningless line drawings. No advantage for synesthetes was found. However, performance was at ceiling after two trials. In addition to these WMS subscales, two modified versions of the Warrington Recognition Memory Test were used. One involved words, the other involved faces. During the study phase, participants were required to rate each item as pleasant or unpleasant, and in a later test phase, 25 old and 25 new items were presented with the instruction to decide whether the item had been presented before or not. Synesthetes performed better than controls with words, but not with the faces. As a

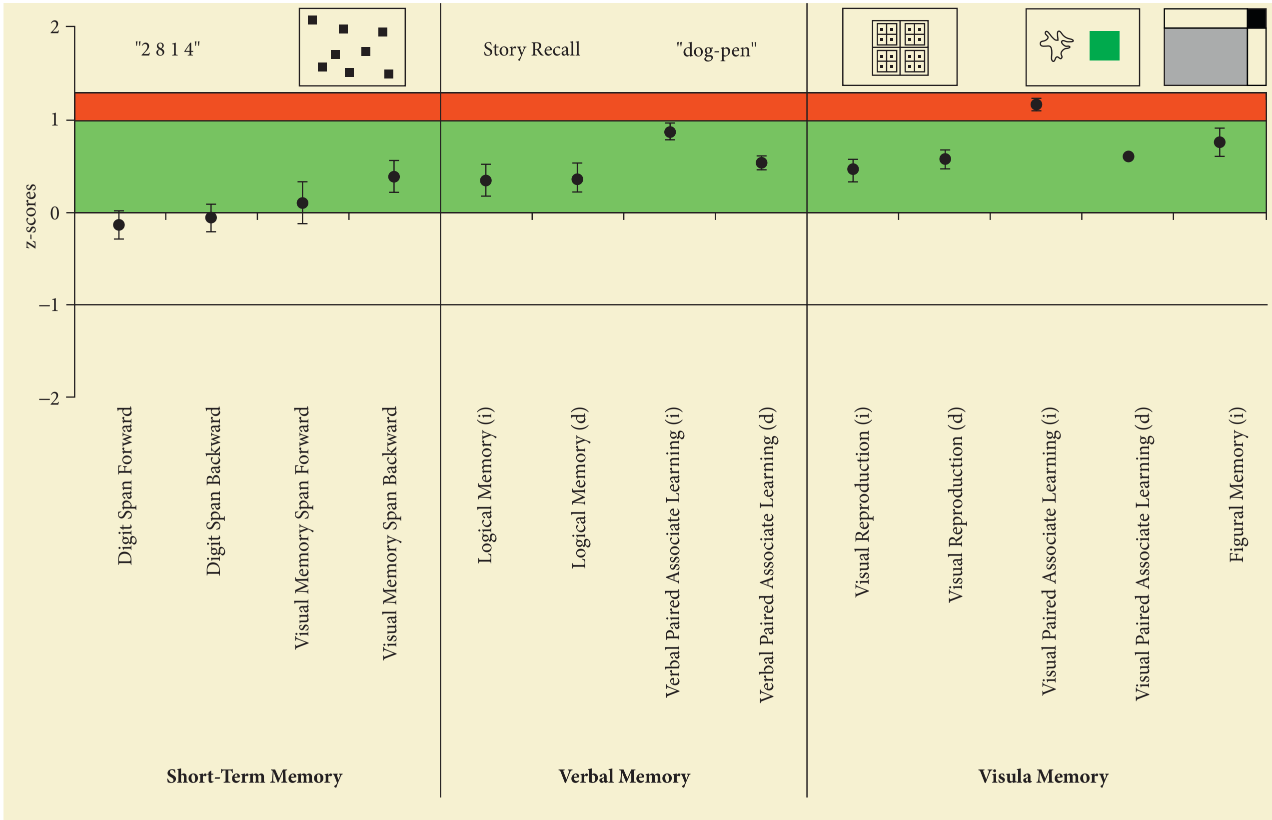

FIGURE 35.1 Profile of synesthetes in each subtest of the Wechsler Memory Scale. The text and images along the top represent examples of the stimulus materials for each sub-test. Values represent mean z-scores, error bars represent standard errors. (i) = immediate test, (d) = delayed test. Adapted from Grapheme–colour synaesthesia yields an ordinary rather than extraordinary memory advantage: Evidence from a group study, Nicolas Rothen and Beat Meier, *Memory*, 18 (3), pp. 258–264 © 2010, Taylor and Francis reprinted by permission of the publisher (Taylor & Francis Ltd, <http://www.tandf.co.uk/journals>).

further measure of verbal memory, the California Verbal Learning Test (CVLT) which has a similar structure as the RAVLT was used. Synesthetes performed better than the control group in the delayed recall but not in the immediate recall conditions. Finally, the RCFT was also used and while Gross et al. (2011) did not find an overall performance difference, they found better performance for synesthetes in the immediate copy subtest, and using a qualitative scoring method they also found higher configural accuracy, that is, higher accuracy for the overall shape of the figure. Together, these results replicate an advantage for synesthetes with verbal materials, and again they suggest that a more general advantage may be present which can extend to the visual domain.

Given that the performance benefit for synesthesia-inducing materials is well-established, an open question is what processes are driving this advantage. One possibility is that the experience of synesthetic colors favors item-specific against relational processing. That is, the synesthetic color experience may increase item-specific processing at the letter and word level separate from semantic meaning, and as a result a decrease in relational processing can occur. This possibility was addressed specifically for word list recall by Radvansky, Gibson, and McNerney (2011). They tested a sample of ten grapheme-color synesthetes in four separate experiments. In the first experiment, they manipulated the print color of the words. In one condition the colors matched the synesthetic color (i.e., congruent condition), in another condition the words were printed in a different color (i.e., incongruent condition) and in a control condition the words were presented in black. Each list consisted of 12 words and each word was presented for 1 s and after each list the participants had to recall the words by typing them into the computer. The results showed a performance advantage for the synesthetes compared to the control group in each condition. Moreover, the synesthetes recalled slightly fewer words in the incongruent than in both the congruent and the control condition while no such difference was found for the control group. In the second experiment, different word lists were used and only one word in each list was presented in color (i.e., in red) in order to test the von Restorff isolation effect (von Restorff 1933). This effect refers to the phenomenon that when one item of a different kind is presented within a list of homogeneous items, memory for this item is enhanced. Compared to the control group, the synesthetes showed a performance advantage for the black words, but no von Restorff effect for the colored word. In contrast the control group showed a performance improvement for the colored words such that their performance nearly reached the level of the synesthetes. Thus, for synesthetes the additional color did not add to performance, presumably because they already experienced colors for all of the words. In a third experiment, Radvansky, Gibson, and McNerney (2011) manipulated distinctiveness semantically and again the synesthetes showed an overall advantage in list recall, but no von Restoff effect. Radvansky and colleagues suggested that the additional color experiences of the synesthetes are based on the physical form of the words (i.e., the letters that make them up) and this results in a shift in emphasis of processing on the lexical surface form of the words at the expense of the word meanings, thereby both increasing item-specific processing and decreasing relational processing. In the fourth experiment, the critical manipulation was that all of the words within a list were strongly related to an unmentioned critical word—a manipulation that typically leads to enhanced false memory for the latter (i.e., the Deese–Roediger–McDermott false memory effect; Deese 1959; Roediger and McDermott 1995). Specifically, when studying a list consisting of words that are associated with "bread" (i.e., butter, food, eat, sandwich, rye, jam, etc.) false recall of "bread" is more likely than when studying a more heterogeneous word list. Once again the results showed a list recall advantage for synesthetes. In addition they showed fewer intrusions (i.e., fewer false memories for the implied but absent words) than the control group. Radvansky, Gibson, and McNerney (2011) took these results as support for the hypothesis that when learning word lists, synesthetes rely more on item-specific processing and less on relational processing. Overall, the results replicate the finding that grapheme-color synesthetes have an advantage for recalling information from the realm of the inducer (i.e., for verbal materials). However, they do not speak against the possibility that synesthesia may yield a more general memory advantage. However, this was not tested.

The main focus of all the previous studies was on declarative explicit memory and on short-term memory, that is, on tasks that required the deliberate recollection of previously encountered information. So far, only one study was designed to test the impact of synesthesia on non-declarative memory. Meier and Rothen (2007) tested a group of 13 grapheme-color synesthetes with a classical conditioning task. Participants were presented with colored squares and occasionally a specific grapheme was presented in black on a white background. The grapheme was selected such that it elicited a particular color experience (e.g., blue). During the conditioning phase, this particular color (i.e., the conditioned stimulus) was followed immediately by a loud startling noise which served as an unconditioned stimulus. All participants showed a startle reaction as indicated by an increase in skin conductance response (SCR) for the unconditioned stimulus. After conditioning, for the synesthetes, but not for the controls, there was also a startle response when a grapheme was presented—although a grapheme was never coupled with the startling sound. Thus, a synesthetic conditioned response occurred. In a further study, it was tested whether this effect can be suppressed by applying transcranial magnetic stimulation (TMS; Rothen et al. 2010). With TMS the functionality of a specific brain area can be temporarily affected by inducing a strong magnetic field. Specifically, TMS was applied over the parieto-occipital cortex during the presentation of the conditioned color stimulus that was followed by the startling sound. The results showed that this eliminated the conditioned response. Thus, implicit activation of the synesthetic inducer during conditioning must be at the core of the synesthetic conditioning effect. To sum up, these results add evidence that synesthesia creates learning opportunities which are not present in non-synesthetes.

Memory in Other Forms of Synesthesia

So far, most of the work has focused on memory in grapheme-color synesthesia. However, similar principles may apply to other forms of synesthesia as well. It is important to note that any form of synesthesia potentially enriches the world of experiences compared to normal and thus, at least for inducers, specific memory advantages might be expected in any form of synesthesia.

Simner, Mayo, and Spiller (2009) recruited a group of ten time-space synesthetes, that is, individuals who see ordered sequences (such as weeks, months, years) in particular spatial arrays. Their goal was to test whether the synesthetes have an advantage in remembering public and autobiographical events, that is, information from the realm of the inducer, and whether they have an advantage in visuo-spatial abilities such as mental rotation and visual memory. A memory test of public events consisted of assigning a correct year to a given event from three different domains (international political events, films, songs). An autobiographical memory test was to list as many facts as possible for 9 different years from their life (the 9 different years were determined individually for each participant; they represented equi-distant years starting from when the participant was 5 years old and ending 3 years prior to taking the test). The results showed that synesthetes were more accurate in dating the public events in each of the three domains and they also recalled more autobiographical events. To test for visuo-spatial abilities, the Benton's test of three-dimensional (3D) praxis, the Progressive Silhouttes subtest from the Visual Object and Space Perception (VOSP) battery, the Visual Patterns Test (VSP), and the California Mental Rotation Test (CMRT) were used. The Benton Test assesses the ability to manipulate objects in 3D space, the VOSP assesses the ability to recognize a 3D object from an unusual two-dimensional (2D) angle, the VSP assesses memory for patterns of black and white squares in grids of varying sizes, and the CMRT assesses the ability to mentally manipulate 2D drawings of 3D objects. In brief, the results revealed that synesthetes outperformed controls (or the respective norm groups) in all of these tests. Thus, this study provides further evidence for the generality of a performance advantage for synesthetes that goes beyond the realm of the inducer and involves the domain of the concurrent as well.

The benefits and Costs of Synesthesia: A Preliminary Summary

Research on memory in synesthesia is still in its infancy. However, the studies reviewed here allow for several tentative conclusions (see Table 35.1). First, there is consistent evidence that a memory advantage can occur in grapheme-color synesthesia, in particular for recalling lists of words and lists of digits. As these materials trigger the synesthetic experience, this supports the hypothesis that the memory advantage is directly linked to the realm of the inducer—at least. It is noteworthy that learning lists of single items provokes an item-specific processing style and it is possible, that this particular benefit of synesthetes may be reduced when words are used in context as in the Logical Memory subscale of the Wechsler Memory Scale.

Importantly, potential costs of synesthesia for memory performance can also be identified at this level. When incongruently colored stimuli were used as the to-be-remembered materials, memory performance was impaired, at least in some studies. However, rather than at the level of memory retrieval, this cost is probably due to weaker encoding (i.e., the physical color does not match the synesthetic color) and probably also on a motivational level ("this is ugly"). However, it is possible that inconsistent results regarding incongruently colored stimuli are also due to individual differences between different types of synesthetes. Possibly, projectors who experience the color "out in the world" may be more affected than associators who experience color "in their mind's eye" (cf. Dixon, Smilek, and Merikle 2004).

Second, in those studies which addressed the question as to whether a memory advantage would extend to the domain of the concurrent, a consistent advantage was found. These results indicate that a simple dual-coding account is not sufficient, because this account would not have predicted a performance advantage for the domain of the concurrent (i.e., the concurrent does not provide for an explicit additional memory code). Rather, a possible explanation is that these results are due to implicit information activation from the concurrent to the inducer. An alternative explanation, which is compatible with the former, is that synesthetes have a more elaborate processing capacity for colors. This idea is plausible given that synesthetes have a very precise representation of the specific color tone of their synesthetic color experiences. Moreover, there is empirical evidence that synesthetes have enhanced sensory perception in the domain of their synesthesia (Banissy, Walsh, and Ward 2009).

Third, at least some studies have reported a benefit for synesthetes for materials that are related neither to the inducer nor the concurrent. One possibility is that these are simply random results. However, given the rather small sample size in most of the studies in which null results were found and the numerical advantage in some of these studies, it is more likely that these results are indeed real (cf. Table 35.1). This would be consistent with the idea that some aspects of the information processing system of synesthetes work fundamentally differently (see Rothen, Meier, and Ward 2012). In fact there is evidence from electroencephalography that synesthetes differ from controls in early visual processing (Barnett et al. 2008). Notably this was found for materials which are not at all related to synesthesia (i.e., high-spatial-frequency patches and high-contrast check pattern). Moreover, results from structural imaging studies also provide evidence that there are altered brain networks in synesthetes (Jäncke et al. 2009; Rouw and Scholte 2007, 2010; Weiss and Fink 2009). It is possible that these differences are directly related to cognitive processes and memory capabilities. Testing this hypothesis will be an attractive avenue for further research.

A further avenue for future research concerns the investigation of other types of synesthesia. So far, most studies have investigated memory in grapheme-color synesthesia, and only one study has tested sequence-space synesthesia. It will be important to replicate and extend the findings from sequence-space synesthesia. However, there are many other forms of synesthesia and it will be important to investigate whether these synesthetes also show enhanced memory performance. Moreover, it will also be important to test whether the presence of multiple synesthesias can additionally boost memory performance.

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