Synaesthesia and enhanced memory performance: A review of the literature

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Abstract

The multi-modal sensory integration that is the experience of synaesthesia has often been affiliated with extraordinary abilities in memory as reflected by Luria's reports of subject "S", Russian mnemonist, Solomon V. Shereshevskii, who had all five senses integrated. This literature review aimed to assess the present evidence of a link between synaesthesia and memory. A wide range of literature was explored, including neuroanatomical evidence, case studies, group studies, and a possible theoretical explanation. In conclusion, the literature indicates a clear link between synaesthesia and greater memory performance, however this link is not as significant as suggested by case studies such as Luria's subject S and appears to be limited within the domain or domains of the specific synaesthetic experience of each synaesthete. Whether memory is improved at encoding, storage or retrieval is discussed as well as a cue-induced theory of synaesthesia and memory. Findings suggest greater memory performance may be due to differences in neuroanatomical structure and/or the synaesthetic experience providing additional cues to memory.

Keywords: Synaesthesia; memory; perception; multi-modal integration; cue-induced theory.

Introduction

Synaesthesia is a phenomenon in which a given stimulus that is responded to by one sensory modality, triggers a secondary sensory experience (percept) from the same or a different sensory modality (Motluk, 1997). An individual who experiences such additional percepts is known as a synaesthete. For instance, when viewing letters of the alphabet written in black ink a synaesthete may experience additional colour percepts associated uniquely to each letter of the alphabet while still remaining aware of the black colour of the text. Synaesthetic experiences are involuntary, automatic, unique and consistent for each synaesthete and have been estimated to occur in ranges as low as one in 200, up to ranges of one in 250,000 individuals (Cytowic, 2002; Sagiv & Ward, 2006). It has been suggested synaesthetic experiences provide an advantage of extraordinary abilities in memory (Sitton & Pierce, 2004). This advantage has been supported by neurological evidence as well as previous case studies and more recent group studies. However, whether this memory advantage is general (across all domains of memory performance) or explicitly associated with the specific synaesthesia experienced is a topic of contention. Furthermore, some studies have attempted to isolate which specific processes of memory are improved (encoding, storage and/or recall). This literature review will explore the evidence of extraordinary synaesthetic memory, whether this memory advantage is general or specific to the type of synaesthesia, what aspects of memory are improved by synaesthesia and lastly, the cue-induced memory advantage theory of why synaesthetes have better memory than non-synaesthetes will be discussed.

Neuroanatomical differences in synaesthetes

Structural differences in synaesthete brains provide evidence of greater connections with areas involved in processing of working memory, suggesting synaesthetes may have greater memory abilities than non-synaesthetes. Rouw and Scholte (2007) found significantly more white matter connections in the superior parietal cortex, right inferior temporal cortex (important in visual object recognition) and frontal regions in 18 synaesthetes using diffusion tensor imaging (DTI). This was further supported by Wiess and Fink (2009) who found 18 synaesthetes had greater grey matter volume in the left intraparietal sulcus (thought to play a role in processing symbolic numerical information) and right fusiform gyrus (found to process words, numbers and some colour) compared to 18 controls. The superior parietal cortex has been found to be critical for the manipulation of working memory (Koenigs, Barbey, Postle, & Grafman, 2009), additionally the intraparietal sulcus is involved in visuospatial working memory (Todd & Marois, 2004). This provides evidence that synaesthetes may have enhanced memory abilities as a reflected by the greater white and grey matter connections between areas involved in memory processing, perceptual processing, and adjacent cortical areas.

Overview of synaesthesia variations

Synaesthesia can occur within one or between multiple sensory modalities, and at least one synaesthete, Solomon Shereshevsky, experienced synaesthesia which combined all five senses (Luria, 1968). From these possibilities it is not surprising that at least 19 variations of synaesthesia have been observed (Jensen, 2007). To avoid ambiguities between this wide range of variations, a notation method of the general form (I) → (C) has been adopted by researchers, where 'I' is the "inducer" or stimuli which triggers the synaesthetic experience, and ‘C’ is the “concurrent” or additional percept. For example, the experience of additional colours given to individual letters of the alphabet can be referred to as letter → colour synaesthesia, or more generally, grapheme → colour (grapheme-colour) synaesthesia.

The most studied variation of synaesthesia is grapheme-colour synaesthesia (Radvansky, Gibson, & McNerney, 2011). It is the most studied as it is the most available form of synaesthesia. It is estimated that 45-65% of all synaesthetes are grapheme-colour synaesthetes (Brown, 2007). As demonstrated by previous examples, grapheme-colour synaesthetes may report seeing a green colour percept when viewing the letter “a” printed in black on white paper (Grossenbacher & Lovelace, 2001). Many grapheme-colour synaesthetes also experience colours for heard words (phomenic- colour) or even thinking about words (Simner, 2007).

Two other of the more common synaesthesia varieties are sound-colour and sequence-space synaesthesia. In sound-colour synaesthesia any sound such as clattering dishes or a dog barking can trigger visual experiences of colour which have been described to appear like fireworks which fade with the cessation of the sound (Cytowic, 2009). In sequence-spatial, or number-form synaesthesia, any stimuli with a sequence such as numbers, days of the week or months of the year are experienced in specific ‘mapping’ locations in space, such as the months of the year may appear to be arranged from right to left surrounding the individual (Galton, 1880; Sagiv, Simner, Collins, Butterworth, & Ward, 2006b). These mappings may exist in the space around the body or in a virtual space within the mind’s eye of the synaesthete.

Apart from the reports of multi-modal synaesthete Solomon Shereshevsky, the relevant literature on synaesthesia and memory performance covered in this review only involve two specific types of synaesthesia: grapheme-colour and sequence-space. When addressing memory as specific to the synaesthetic experience, grapheme-colour synaesthesia would be expected to produce better memory for visual or verbal graphemes depending on whether their synaesthetic percept is produced in response to visual or verbal (phonemic-colour) stimuli and, sequence-space synaesthesia would be expected to be better for visuo-spatial tasks in memory (Gross, Neargarder, Caldwell-Harris, & Cronin-Golomb, 2011).

Early evidence surrounding synaesthesia and memory performance: Case studies

The suggestion of a possible link between synaesthesia and memory stemmed from the 1968 writings of Alexander Luria, a neuropsychologist who wrote about subject “S”. S was Russian mnemonist, Solomon V. Shereshevskii who had all five senses perceptually integrated. He could remember complex figures and matrices of 50 digits after studying them for only a few minutes and was able to recall both years later (Luria, 1968). Luria suggested S’s extraordinary memory was at least in part a result of his multiple synaesthesia.

Smilek et al. (2002) conducted a more recent case study on grapheme-colour synaesthete “C”, whose synaesthesia was specific to digits. C was tested with digit matrices, one with black digits, another congruent (digit colours equal to C’s synaesthetic percepts) and a third incongruent (digit colours non-equal to C’s synaesthetic percepts). When tested immediately, C showed significantly better performance than the control group on both the black and congruent matrices however, her recall for the incongruent matrix was below average. This demonstrates how stimuli incongruent with synaesthesia can disrupt memory because the synaesthetic percept cannot be ignored and interferes (Mills, Boteler, & Oliver, 1999; Odgaard, Flowers, & Bradman, 1999) and also that memory may only be enhanced for stimuli which elicits a synaesthetic response. Smilek et al. also tested C after 48 hours on the black matrix and she exhibited no decline in performance while the control group exhibited a significant decrease. The authors suggested synaesthetic percepts provide additional memory cues and hence played an essential role in C's memory abilities.

Mills et al. (2006) tested a grapheme-colour synaesthete "MLS" across a range of different memory tests against a matched control group and found MLS performed significantly better in verbally-related (associate learning and list learning) tests and was not significantly different from controls on visual (complex figure rest) tests. MLS also reported utilising her synaesthetic percept to remember names and verbal material. Mills et al. suggested memory advantages in synaesthetes do not generalise to information that do not elicit the synaesthetic experience. This implies memory advantages in synaesthetes may be specific to the synaethetes' specific synaesthesia rather than a general or overall memory benefit of synaesthesia.

Overall, the evidence presented by Luria's account of Solomon Shereshevskii suggests synaesthesia provides a general memory benefit. This is not supported by the case studies presented by Smilek et al. (2002) and Miller et al. (2006) both of which suggest synaesthetes only exhibit advantageous memory performance for tasks which elicit a synaesthetic percept. Notably, although Luria's account of S appears to support a general memory benefit, since S's synaesthesia involved all five sensory modalities integrated, this finding could also support memory performance is only enhanced for tasks which elicit synaesthetic percepts since S would experience synaesthetic percepts in response to all stimuli. This finding may be true but an important limitation of case studies must be acknowledged. The synaesthetes S, C and MLS were selected due to their demonstrated extraordinary memory performance (Rothen & Meier, 2010a). This selection method may provide a biased perspective of the memory performance of other synaesthetes and in turn limits the generalisability of results to other synaesthetes. Hence, studies testing memory performance of groups of synaesthetes may be more indicative of the true relationship between synaesthesia and memory.

Group studies surrounding synaesthesia and memory performance

There are two possible memory benefits provided by synaesthesia outlined by the above case studies, either synaesthetes have generally better memory overall i.e. general memory benefits (Luria, 1968), or memory performance is only better than non-synaesthetes for tasks that elicit a synaesthetic percept (Mills, et al., 2006; Smilek, et al., 2002). The evidence supporting these two perspectives within studies assessing groups of synaesthetes is discussed below.

General memory benefit of synaesthesia

Yaro and Ward (2007) were the first to assess synaesthesia and memory with a group of synaesthetes. The authors tested a large sample of 46 grapheme-colour synaesthetes and 46 controls and found most synaesthetes (70%) believed their synaesthesia helped their memory and were found to frequently use visual strategies to aid memory compared to the control group. The authors further tested 16 synaesthetes and 16 controls on one verbal and two visuo-spatial memory tests; the Rey Auditory Verbal Learning Test, Farnsworth-Munsell Colour Test, and Rey-Osterieth Complex Figure Test respectively (see Yaro & Ward, 2007 for more information). The results found synaesthetes had significantly better memory performance for colours and for words eliciting synaesthetic colours compared to controls, and this difference was more pronounced after a delay. From this finding Yaro and Ward suggested the memory performance advantage of synaesthetes is due to improved storage rather than improved encoding. In all other tests (including the congruent digit matrix), no memory advantage was found for synaesthetes over the control group, which included a congruent digit matrix. This specific finding implies tasks which are related to the synaesthetic experience (in this case, digits) may not produce better memory performance. This directly contrasts Smilek et al.'s (2002) finding that a congruent digit matrix produced better memory recall compared to a control group for synaesthete C. Furthermore, the implication of Yaro and Ward's results provides evidence against the theory that synaesthetic memory is better for tasks that elicit a synaesthetic percept. Instead, Yaro and Ward hypothesised greater memory performance in synaesthetes is specific to colour across both synaesthetic and non-synaesthetic stimuli, supporting a partially general advantage of memory in synaesthetes. However, it should be noted that this hypothesis only appears to be applicable to grapheme-colour synaesthetes.

Gross et al. (2011) assessed if better memory performance of grapheme-colour synaesthetes is specific to verbal memory tests which should trigger synaesthesia as opposed to visuo-spatial tests which should not. They found synaesthetes demonstrated significant memory advantages in the synaesthetic-related domain of verbal tasks and also found a synaesthetic memory advantage on visuo-spatial tasks providing support for a general advantage of memory rather than domain specific. This result is consistent with Yaro and Ward's (2007) finding that synaesthetes' memory is not specific to synaesthetic ability. However, Gross et al.'s (2011) study did not control for potential overlap between their sample of grapheme-colour synaesthetes and other forms of synaesthesia. Studies have shown significant overlap between sequence-space synaesthesia and grapheme-colour synaesthesia (Sagiv, Simner, Collins, Butterworth, & Ward, 2006a). Also, individuals with synaesthesia involving vision have often been found to have better visuo-spatial skills than non-synaesthetes (Price, 2009). If this overlap was present in Gross et al.'s sample the results would no longer suggest a general advantage of memory in synaesthetes. Upon closer inspection of Gross et al.'s study it appears grapheme-colour synaesthesia did overlap with sequence-space synaesthesia. Gross et al. noted some synaesthetes in their sample reported experiencing percepts of spatially based calendars (Gross, et al., 2011) which is characteristic of sequence-space synaesthesia. Therefore, since it appears Gross et al.'s sample did contain sequence-space synaesthetes, their findings support the hypothesis that the memory advantage of synaesthetes is specific to the type of synaesthesia rather than general. To better verify this claim, a review of group studies which compare aspects of memory that would and would not be expected to elicit a synaesthetic response is warranted.

Synaesthetic specific memory advantage

Rothen and Meier (2009) assessed memory performance using an incongruent digit matrix and a black digit matrix. The authors tested memory in a group sample of 13 grapheme-colour synaesthetes and 13 controls; immediately, after 30 minutes, and after two to three weeks. The incongruent digit matrix was expected to interfere with synaesthetic memory performance based on the findings by Smilek et al. (2002); whereas, the black digit matrix was expected to elicit a synaesthetic response. No significant memory advantage was found for synaesthetes compared to controls across all three testing points for both matrices. From the results of this study, Rothen and Meier suggested synaesthesia does not lead to a memory performance advantage. However, this claim seems premature as they only assessed two matrices and no other tests of memory performance.

Following from their previous study, Rothen and Meier (2010a) tested a larger sample of 44 grapheme-colour synaesthetes with the German version of the revised Wechsler Memory Scale (WMS-R) (Härting et al., 2000) to assess if synaesthetes have a general memory advantage. These synaesthetes were compared to the normative sample consisting of seven age groups with thirty participants in each. Only one (Visual Memory Span Backward) of four short-term memory subtests was found to be significant. Across the other subtests and memory indices a consistent advantage was found in verbal memory and visual memory, however this advantage was mostly within ordinary range, on average (Rothen & Meier, 2010a). A paired-samples t-test showed scores on the visual index were significantly higher than the verbal index, thus synaesthetes showed a particular memory benefit for visual stimuli. Rothen and Meier's results provide strong evidence against Yaro and Ward's (2007) colour-specific memory advantage hypothesis since the majority of visual memory subtests of the WMS-R used are not related to colour but still resulted in significantly better memory performance in synaesthetes. Rothen and Meier instead suggested synaesthetes only show memory advantages congruent with their synaesthetic percept which they called an "island of ability".

Addressing the inconsistent evidence surrounding congruent colour matrices, Radvansky et al. (2011) tested 10 grapheme-colour synaesthetes and found lower memory performance on the incongruent colour matrix compared to the congruent colour matrix. Notably, Radvansky et al. found synaesthetes performed better than controls on the incongruent matrix, which differed from Smilek et al. (2002) who found synaesthetes had poorer performance compared to controls for incongruent matrix due to interference of their synaesthetic percept. This finding suggests that interferences of synaesthetic percepts for tasks which do not trigger a percept are not as influential are previously suggested.

Furthermore, the findings suggest synaesthesia does provide a memory advantage, in which performance is specifically better for stimuli which do elicit the synaesthetic percept, rather than those that may interfere.

Further supporting memory advantages being specific to stimuli which trigger synaesthetic percepts, Simner, Mayo and Spiller (2009) assessed a sample of 10 sequence-space synaesthetes across various tasks relating to time and visualised space, and one task the NART (Nelson, 1982), a reading ability task. Each synaesthete was compared to two controls matched by age, sex, nationality and educational background. Simner et al. demonstrated sequence-space synaesthetes had superior cognitive performance for tasks which related to their mental calendars involving visuo-spatial and episodic memory; however their performance was not superior for the NART, which did not drawn on abilities related to their mental calendars. Although this study did not assess memory directly, it demonstrated better performance in synaesthetes tends to only occur specifically within areas which relate to the variation of synaesthesia.

The association between an individual's synaesthetic percept and heightened abilities is not unique to memory or cognitive performance. Many studies have found a larger proportion of synaesthetes in creative arts (Domino, 1989; Mulvenna & Walsh, 2005; Rothen & Meier, 2010b; Simner et al., 2006). Notably, Ward, Thompson-Lake, Ely and Kamanski (2008) found synaesthetes have a tendency to spend more time engaged in creative arts and the type of creative arts was often consistent with the type of synaesthesia, for example synaesthetes experiencing vision from music were more likely to play an instrument than other synaesthetes. Hence, synaesthetes appear to have an overall inclination toward adopting their synaesthetic ability to assist their performance wherever possible.

In summary, group studies comparing stimuli which are expected to elicit synaesthetic percepts compared to unrelated tasks demonstrate a memory advantage which is greater than non-synaesthetes. Although, the one study by Rothen and Meier (2009)did not find a memory advantage for tasks that would be expected to elicit a synaesthetic response, a study by the same authors (Rothen & Meier, 2010a) and a study assessing the same stimuli (colour digit matrices) (Radvansky, et al., 2011) both demonstrate a synaesthesia-specific memory advantage. Additionally, the study by Radavansky et al. (2011) demonstrated a memory advantage was present even when the colour digit matrix produced interferences with the synaesthetic experience. Furthermore, other studies suggest that synaesthetes typically demonstrate better performance which is directly related to their synaesthetic experience (Simner, et al., 2009; Ward, et al., 2008).

The specifics: Where in memory processing does the advantage occur?

Within the present literature, it seems the link between synaesthesia and advantageous memory performance restricted to tasks related to an individual's specific synaesthesia is becoming an accepted perspective. The new debate surrounding synaesthesia and memory is addressing the question of which aspect of memory is being enhanced specifically: encoding, storage or recall?

Gross et al. (2011) assessed whether memory performance was greater in the short-term (encoding) or after a delay (recall). They found the differences between controls and synaesthetes were most prominent when compared after a short delay following test administration rather than longer delays. For instance they found synaesthetes only demonstrated better memory performance on the two earliest recall periods for the Paired Verbal Associates subtest (see Gross, et al., 2011 for more details), and the largest difference between synaesthetes and controls on the Rey-Osterrieth Complex Figure occurred when the figure was shown and immediately copied (the 'copy condition'), which served as the encoding trial. These findings suggest synaesthetes have superior memory encoding rather than recall compared to controls.

Conversely, some studies have failed to find any significant short-term memory advantages (Bor, Bilington, & Baron-Cohen, 2007; Rothen & Meier, 2010a) and only recall performance was enhanced for synaesthetes (Rothen & Meier, 2010a). Furthermore, memory performance has been found to improve with delay (Yaro & Ward, 2007). From these findings, Yaro and Ward (2007) hypothesised that better synaesthetic memory performance is due to better storage rather than improved encoding or recall. Other studies support superior recall is responsible for better memory performance in synaesthetes (Mills, et al., 2006; Smilek, et al., 2002). Clearly, the present evidence between the encoding, storage and recall hypotheses is limited and conflicting. Exactly which aspects of memory are enhanced by synaesthesia remains unclear and would benefit from further research. Assessing coping or other short-term tasks as a measure of encoding could arguably be considered a measure of recall, as the manipulation is the time after encoding not the encoding period itself. Instead, perhaps assessing the duration of learning time required to accurately recall a certain digit matrix may provide a better indication of encoding abilities, where less time required to produce accurate recall of a digit matrix would reflect more effective encoding. Assessing encoding in this way may help establish a clearer distinction between encoding and recall in relation to synaesthesia and memory performance. Whether recall improves with increased delay would be a clear indication of better storage rather than better recall. Furthermore, comparing memory performance differences between variations of synaesthesia has not been assessed and may reveal specific memory processes are better for certain types of synaesthesia. For example, due to the visual calendars associated with sequence-space synaesthetes, the virtual calendar experienced may assist in long-term memory recall.

A possible cue-induced memory advantage of synaesthesia

Regardless of whether memory encoding, storage or recall is enhanced due to synaesthesia, the association between enhanced memory performance being specific to synaesthetic experience remains. Better memory performance in synaesthetes appears to be limited to stimuli that trigger synaesthetic percepts (Gross, et al., 2011; Mills, et al., 2006; Radvansky, et al., 2011; Rothen & Meier, 2010a; Smilek, et al., 2002). Varying perspectives provided by the studies supporting this finding seem to converge on the same point; the synaesthetic percept produced provides an additional cue to memory. Gross et al. (2011) proposed the cue-induced encoding/retrieval hypothesis, in which the cue provided by synaesthetic percepts can be consciously utilised to assist encoding and recall. It appears the utilisation of the synaesthetic percept as a cue is a conscious process. Synaesthetes have often said they employ their synaesthetic percepts to help complete memory tasks (Mills, et al., 2006; Simner, et al., 2009; Yaro & Ward, 2007).

Although the cue-induced theory is supported by studies which give varying and conflicting evidence on which specific aspect of memory is enhanced (Gross, et al., 2011; Mills, et al., 2006; Rothen & Meier, 2010a; Smilek, et al., 2002), Rothen and Meier (2010a) provide a good argument as to why their results only found an advantage for long-term recall rather than short-term memory. They based their argument on the premise that when completing short-term memory tasks the stimuli which would elicit synaesthetic percepts would need to be actively held in memory. Hence, when completing short-term memory tasks, additional retrieval cues may not necessarily be produced and in turn would not be available to assist in short-term memory performance (Rothen & Meier, 2010a). As mentioned earlier, further research is required to clarify which aspect of memory is enhanced in synaesthesia, and in doing so the relationship between synaesthesia and memory can be better understood.

Evidence against the cue-induced memory advantage of synaesthesia is demonstrated by the pattern of clustering adopted by synaesthetes. Savage et al. (2001) found the use of clustering to encode information is associated with improved memory. This suggests, synaesthetes may adopt patterns of information clustering which are unique to non-synaesthetes. Gross et al. (2011) argued if synaesthetes relied primarily on their synaesthetic cues this should be reflected in their semantic clustering, however, synaesthetes were found to employ similar strategies to controls suggesting grapheme-colour synaesthetes use conventional methods of verbal organisation (Gross, et al., 2011). Radavansky et al. (2011) also found synaesthetes were not organising their recall by their synaesthetic experience, in this specific instance, colour. Upon debriefing, Yaro and Ward (2007) found two out of the 16 synaesthetes assess on memory tasks reported using an overt back-translation strategy for remembering colour matrices. However, upon observing these two synaesthetes performance relative to the rest of the sample this strategy does not appear to have provided any additional advantage (Yaro & Ward, 2007). Hence, overall it does not appear as if synaesthetes adopt a clustering method unique to their synaesthesia and in turn, this finding provides evidence against a cue-induced theory of synaesthesia.

Notably, the above evidence was all additional information gathered within studies focusing on memory performance and synaesthesia overall. A study focusing on the specific clustering strategies used by synaesthetes compared to non-synaesthetes may provide clearer and more definitive evidence as to whether the above findings are supported. Furthermore, it would be interesting to assess whether differences in clustering strategies exist between different varieties of synaesthesia.

Conclusions

Although the link between synaesthesia is not as general and significant as reflected by Luria's reports of S, a clear link between synaesthesia and greater memory performance is present in the literature and has especially become more evident in recent years. This enhanced memory performance may be due to greater connections between perceptual processing areas and areas involved in processing working memory as well as synaesthetic percepts providing additional cues to memory. Overall, case studies and group studies appear to present a stronger argument for a memory advantage in synaesthetes being specific to tasks which elicit synaesthetic percepts. Whether memory is enhanced at encoding, storage or recall remains unclear and it was suggested that a more direct manipulation of encoding may help clarify this ambiguity. This evidence has led to cue-induced theories of synaesthesia and memory performance, in which synaesthetic percepts can be consciously adopted as additional cues to memory. However the present evidence of the clustering strategies adopted by synaesthetes suggests perhaps a cue-induced theory is not correct. An increasingly intricate understanding of the unique association between synaesthesia and memory performance will undoubtedly be established in future research and in turn the greater understanding of the role of memory in synaesthesia will contribute to a better understanding of human memory processing in general.

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References

Bor, D., Bilington, J., & Baron-Cohen, S. (2007). Savant memory for digits in a case of synaesthesia and Asperger syndrome is related to hyperactivity in the lateral prefrontal cortex. *Neurocase: Case Studies in Neuropsychology, Neuropsychiatry, and Behavioural Neurology, 13*, 311-319.

Brown, E. (2007). Exploring implications of synesthesia on memory. 19. Retrieved from http://digitalcommons.pace.edu/honorscollege_theses/62

Cytowic, R. E. (2002). *Synesthesia: A union of the senses* (2nd ed.). Cambridge MA: MIT Press.

Cytowic, R. E. (2009). *Wednesday is indigo blue: Discovering the brain of synesthesia*. Cambridge MA: MIT Press.

Domino, G. (1989). Synaesthesia and creativity in fine arts students: An empirical look. *Creativity Research Journal, 2*, 17-29.

Galton, F. (1880). Visualized numerals. *Nature, 22*(543), 494-495.

Gross, V. C., Neargarder, S., Caldwell-Harris, C. L., & Cronin-Golomb, A. (2011). Superior encoding enhances recall in color-graphemic synesthesia. *Perception, 40*, 196-208.

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

Härting, C., Markowitsch, H. J., Neufeld, H., Calabrese, P., Deisinger, K., & Kessler, J. (2000). *Wechsler Gedächtnistest-Revidierte Fassung (WMS-R), Test manual, deutsche Adaptation der revidierten Fassung der Wechsler Memory Scale von David Wechsler*. Bern: Hans Huber.

Jensen, A. (2007). Synesthesia. *Lethbridge Undergraduate Research Journal, 2*(1).

Koenigs, M., Barbey, A. K., Postle, B. R., & Grafman, J. (2009). Superior parietal cortex is critical for the manipulation of information in working memory. *The Journal of Neuroscience, 25*(47), 14980-14986.

Luria, A. R. (1968). *The mind of a mnemonist: A little book about a vast memory. Translated by Lynn Solotaroff*. Cambridge MA: Harvard University Press.

Mills, C. B., Boteler, E. H., & Oliver, G. K. (1999). Digit synaesthesia: A case study using a stroop-type test. *Cognitive Neuropsychology, 16*(2), 181-191.

Mills, C. B., Innis, J. A., Westendorf, T., Owsianiecki, L., & McDonald, A. (2006). Effect of a synesthete's photisms on name recall. *Cortex, 42*, 155-163.

Motluk, A. (1997). Two synaesthetes talking colour. In S. Baron-Cohen & J. Harrison (Eds.), *Synesthesia: Classic and Contemporary Readings* (pp. 269-277). Blackwell.

Mulvenna, C., & Walsh, V. (2005). Synaesthesia. *Current Biology, 15*, R399-R400.

Nelson, H. E. (1982). *National Adult Reading Test (NART): Test Manual*. Windsor, UK: NFER Nelson.

Odgaard, E. C., Flowers, J. H., & Bradman, H. L. (1999). An investigation of the cognitive and perceptual dynamics of a colour-digit synaesthete. *Perception, 28*(5), 651-664.

Price, M. (2009). Spatial forms and mental imagery. *Cortex, 45*, 1229-1245.

Radvansky, G. A., Gibson, B. S., & McNerney, M. W. (2011). Synesthesia and memory: Color congruency, von Restorff, and false memory effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(1), 219-229.

Rothen, N., & Meier, B. (2009). Do synesthetes have a general advantage in visual search and episodic memory? A case for group studies. *PLos One, 4*, e5037.

Rothen, N., & Meier, B. (2010a). Grapheme-colour synesthesia yields an ordinary rather than extraordinary memory advantage: Evidence from a group study. *Memory, 18*, 258-264.

Rothen, N., & Meier, B. (2010b). Higher prevalance of synaesthesia in art students. *Perception, 39*, 718-720.

Rouw, R., & Scholte, H. S. (2007). Increased structural connectivity in grapheme-color synesthesia. *Nature Neuroscience, 10*, 792-797.

Sagiv, N., Simner, J., Collins, J., Butterworth, B., & Ward, J. (2006a). What is the relationship between synaesthesia and visual-spatial number forms? *Cognition, 101*, 114-128.

Sagiv, N., Simner, J., Collins, J., Butterworth, B., & Ward, J. (2006b). What is the relationship between synaesthesia and visuo-spatial number forms? *Cognition, 101*(1), 114-128.

Sagiv, N., & Ward, J. (2006). Cross-modal interactions: Lessons from synesthesia. *Progress in Brain Research, 155*, 259-271.

Savage, C. R., Deckersbach, T., Heckers, S., Wagner, A. D., Schacter, D. L., Alpert, M. N., et al. (2001). Prefrontal regions supporting spontaneous and directed application of verbal learning strategies: Evidence from PET. *Brain, 124*, 219-231.

Simner, J. (2007). Beyond perception: Synaesthesia as a psycholinguistic phenomenon. *Trends in Cognitive Sciences, 11*, 23-29.

Simner, J., Mayo, N., & Spiller, M.-J. (2009). A foundation for savantism? Visuo-spatial synesthetes present with cognitive benefits. *Cortex, 45*, 1246-1260.

Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S. A., Fraser, C., et al. (2006). Synaesthesia: The prevalence of atypical cross-modal experiences. *Perception, 35*, 1024-1033.

Sitton, S. C., & Pierce, E. R. (2004). Synesthesia, creativity and puns. *Psychological Reports, 95*(2), 577-580.

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

Todd, J. J., & Marois, R. (2004). Capacity limit of visual short-term memory in human posterior parietal cortex. *Nature, 428*(6984), 751-754.

Ward, J., Thompson-Lake, D., Ely, R., & Kaminski, F. (2008). Synaesthesia, creativity and art: What is the link? *British Journal of Psychology, 99*, 127-141.

Wiess, P. H., & Fink, G. R. (2009). Grapheme-colour synaesthetes show increased grey matter volumes of parietal and fusiform cortex. *Brain, 132*, 65-70.

Yaro, C., & Ward, J. (2007). Searching for Shereshevskii: what is superior about the memory of synaesthetes? *Quarterly Journal of Experimental Psychology, 60*, 681-695.