Research Report

SYNESTHETIC COLOR EXPERIENCES INFLUENCE MEMORY

Daniel Smilek, Mike J. Dixon, Cera Cudahy, and Philip M. Merikle

University of Waterloo, Waterloo, Ontario, Canada

Abstract—*We describe the extraordinary memory of C, a 21-year-old student who experiences synesthetic colors (i.e., photisms) when she sees, hears, or thinks of digits. Using three matrices of 50 digits, we tested C and 7 nonsynesthetes to evaluate whether C's synesthetic photisms influence her memory for digits. One matrix consisted of black digits, whereas the other two matrices consisted of digits that were either incongruent or congruent with the colors of C's photisms. C's recall of the incongruently colored digits was considerably poorer than her recall of either the black or the congruently colored digits. The 7 nonsynesthetes did not show such differences in their recall of the matrices. In addition, when immediate recall of the black digits was compared with delayed recall of those digits (48 hr), C showed no decrease in performance, whereas each of the nonsynesthetes showed a significant decrease. These findings both demonstrate C's extraordinary memory and show that her synesthetic photisms can influence her memory for digits.*

In this article, we describe the extraordinary memory of C, a 21-year-old female student at the University of Waterloo. We first met C following a demonstration, conducted in an introductory psychology class, designed to show the limits of human memory. As part of this demonstration, students participated in a standard memory span task. The students were asked to recall four lists of nine digits that were read to them at a rate of approximately one digit per second. As expected, when the students were asked to raise their hands to indicate the average number of digits that they had recalled from each list, the majority of the students reported that their average recall was six, seven, or eight digits. However, at the end of the class, approximately 2 hr later, C approached the instructor and stated that she could recall all four lists of digits. To the surprise of the instructor, her recall of the lists was almost perfect—her only mistake involved a confusion between the order of two items in one of the lists. Even more intriguing was the fact that C's memory for the digits did not seem to diminish over time. Approximately 2 months after the initial classroom demonstration, we surprised C by asking her to recall the digit lists presented during that class demonstration. She recalled all of the lists correctly with the exception of two items in one list.

Although C's memory performance is clearly beyond the range of normal memory abilities, her performance is not altogether unique. There are a number of case studies that describe individuals who show memory performance similar to C's performance (e.g., Ericsson, Chase, & Faloon, 1980; Wilding & Valentine, 1997). What is unique about C, however, is her description of how she memorizes digits. When asked how she remembered so many digits, she reported that for her, each digit has a specific color, and it is the colors that make it easy for her to remember the digits.

C's description of her subjective experiences indicates that she has digit-color synesthesia. In this form of synesthesia, each digit elicits a unique and highly specific color experience (i.e., a photism). Our initial studies of C revealed that as is the case with other digit-color synesthetes (e.g., Mattingley, Rich, Yelland, & Bradshaw, 2001; Odgaard, Flowers, & Bradman, 1999), her digit-color pairings do not change over time and her photisms occur automatically (Dixon, Smilek, Cudahy, & Merikle, 2000). Our studies also revealed that C experiences photisms whenever she sees, hears, or even thinks of a digit (Dixon et al., 2000; Smilek, Dixon, Cudahy, & Merikle, 2002). When C hears or thinks of a digit, the accompanying photism is experienced "in her mind's eye." However, when she sees a black digit, her photism for the digit is experienced as a color overlaying the digit. Thus, C's photisms influence her perception of visually presented digits (Smilek, Dixon, Cudahy, & Merikle, 2001).

C's statements indicating that her photisms help her to remember digits suggest that her synesthesia contributes to her extraordinary memory performance. Although synesthesia is currently receiving considerable attention (e.g., Dixon et al., 2000; Mattingley et al., 2001; Ramachandran & Hubbard, 2001; Smilek et al., 2001), there is no strong empirical evidence supporting the idea that synesthesia actually improves memory. Perhaps the strongest link between synesthesia and extraordinary memory performance was reported by Luria (1968). In his classic monograph, Luria described many extraordinary memory feats of the professional mnemonist Shereshevsky (S), who was also a synesthete. For example, when S studied a matrix of 50 digits for 3 min, he was able to recall the 50 digits perfectly both immediately after studying the list and many years later. Luria speculated that S's memory abilities were the result of his synesthesia. However, as noted previously (Ericsson & Chase, 1982; Wilding & Valentine, 1997), Luria did not provide any empirical evidence supporting the idea that S's synesthesia contributed directly to his memory abilities.

The purpose of the present study was to document C's extraordinary memory for digits and to evaluate whether C's synesthetic photisms contribute directly to her memory for digits. C and 7 nonsynesthetes were presented with three 50-digit matrices and asked to recall the digits in each matrix immediately following their presentation. The critical difference between the matrices was the color in which the digits were presented. One matrix consisted of black digits. A second matrix was composed of digits displayed in colors that were *incongruent* with C's photisms for the digits, and a third matrix consisted of digits displayed in colors that were *congruent* with C's photisms for the digits. We reasoned that if C's photisms influence her memory for digits, then the digits displayed in incongruent colors would interfere with her memory. Therefore, C's memory for the matrix of incongruently colored digits would be impaired relative to her memory for either the matrix of black digits or the matrix of digits presented in colors that were congruent with her photisms. As a test of C's long-term memory for digits, we also tested her recall of the matrix of black digits following a 48-hr delay.

Address correspondence to Daniel Smilek, Department of Psychology, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1; e-mail: dsmilek@watarts.uwaterloo.ca.

METHOD

Participants

C and 7 nonsynesthetes who were undergraduate students at the University of Waterloo, Waterloo, Ontario, Canada, participated in two 40-min experimental sessions. All nonsynesthetes were questioned about whether they had ever experienced colors when viewing digits or letters. None reported any synesthesia-like experiences. Both C and the nonsynesthetes had normal or corrected-to-normal vision and were paid $15 on completion of the two sessions.

Stimulus Displays

Three different matrices of digits were presented to each participant. Each matrix consisted of 50 randomly generated digits (0 to 9) organized in a display of 10 rows and 5 columns. One matrix consisted of black digits, whereas the other two matrices consisted of colored digits that were either congruent or incongruent with the colors of C's photisms for the digits. The colors of C's photisms were assessed prior to the experiment. Each digit was presented in black beside a color-adjustable square, and C adjusted the color of the square to match the color of her photism for the digit. Using this photism-video color-matching procedure, we established that the colors of her photisms for the digits were the following: 0-gray, 1-white, 2-red, 3-purple, 4-blue, 5-green, 6-pink, 7-yellow, 8-black, and 9-orange. These digit-color pairings were used to construct the matrix of congruently colored digits. For the matrix of incongruently colored digits, the following digit-color pairings were used: 0-white, 1-red, 2-purple, 3-blue, 4-green, 5-pink, 6-yellow, 7-black, 8-orange, and 9-gray.

The matrices of digits were presented at the center of a ViewSonic 17PS monitor that was driven by a 200-MHz Pentium processor running the Micro Experimental Laboratory software (Schneider, 1990). Each digit in each matrix measured 0.3 cm (0.3°)[1] in width and 0.6 cm (0.6°) in height. Each matrix measured 4.5 cm (4.5°) in width and 9.7 cm (9.7°) in height. The digits in each matrix were equally spaced and presented against a light-gray background. The same three matrices were presented to all participants.

Procedure

The participants were instructed to study each matrix for 3 min and to commit as many digits as possible to memory. Following the 3-min study period, the participants were given a 3-min recall period during which they were asked to report as many of the digits as they could remember by filling in the squares of a matrix printed on a sheet of paper. After the recall period, the participants were shown the matrix again for 3 min, followed by another 3-min recall period. Participants cycled through these study and recall periods until the matrix had been studied and recalled a total of four times.

The three matrices were presented in the same order to all participants. On the 1st day of testing, the participants were presented with the matrix of black digits (four times) and then presented with the matrix of incongruently colored digits (four times). Two days later, the participants were asked to recall as many digits as possible from the matrix of black digits presented on the 1st day of testing. The participants were then presented with the matrix of congruently colored digits, cycling through the 3-min study and recall periods until the congruent matrix had been studied and recalled a total of four times.

RESULTS AND DISCUSSION

Figure 1 shows each participant's percentage of correct recall following the first presentation of each matrix. The most important aspect of the data presented in the figure is the contrast between C's recall of the black digits and her recall of the incongruently colored digits. As shown, her recall of the black digits (66%) was higher than the recall of any of the nonsynesthetes (12%–62%). In contrast, her recall of the incongruently colored digits (4%) was strikingly poorer than her recall of the black digits, $\chi^2(1, N = 100) = 42.24$, $p < .001$, and considerably lower than the recall of any of the nonsynesthetes (18%–44%). For each participant, the difference in percentage of correct recall between the black matrix and the incongruently colored matrix was calculated. For the 7 nonsynesthetes, the differences ranged from −20% to +20%, with an average difference of −0.9%. For C, the difference between the black and incongruently colored matrices was 62%—a value that was 5.1 *SD*s greater than the mean difference for the 7 nonsynesthetes.

C's reactions to her experiences when trying to remember the incongruently colored digits were also revealing. Immediately after the matrix of incongruently colored digits was removed from the screen, a horrified expression came over C's face and she exclaimed, "Oh my God! I have never had this happen to me before! I don't think that I can even remember one! What did you do to my memory? I just have all these numbers swirling around in my head! As soon as it [the matrix] went off the screen it was gone! Where did it go?" Later, she stated that as soon as the matrix of digits was removed, "there was nothing there to hold on to." Taken together, both the experimental data and C's reactions to her experiences strongly suggest that C's synesthetic photisms play an integral role in her memory for digits.

The difference between C's recall of the black digits and her recall of the incongruently colored digits was not due to her having trouble memorizing colored digits. If this had been the case, then C should have also found it difficult to memorize and recall the congruently colored digits. However, as shown in Figure 1, her recall of the congruently colored digits was very good, surpassing the performance of 6 of the 7 nonsynesthetes. For each participant, the difference in percentage of correct recall between the congruently and incongruently colored matrices was calculated. For the 7 nonsynesthetes, this congruent-incongruent difference ranged from −6% to 30%, with an average difference of 8%.[2] For C, the congruent-incongruent difference was 44%, a value that was 2.6 *SD*s greater than the mean difference for the 7 nonsynesthetes. Thus, C did not show a reduction in recall for colored digits in general. Rather, only the incongruently colored digits disrupted her recall. We believe that these findings provide further evidence that C's synesthetic photisms strongly influence her memory for digits.

1. Degrees of visual angle subtended are reported for the viewing distance of 57 cm.

2. Inspection of Figure 1 indicates that the nonsynesthetes recalled the congruently colored digits slightly better than they recalled the black and incongruently colored digits. Given that the study and recall of the congruently colored digits followed study and recall of the black and incongruently colored digits, the slightly better recall of the congruently colored digits is likely due to practice.

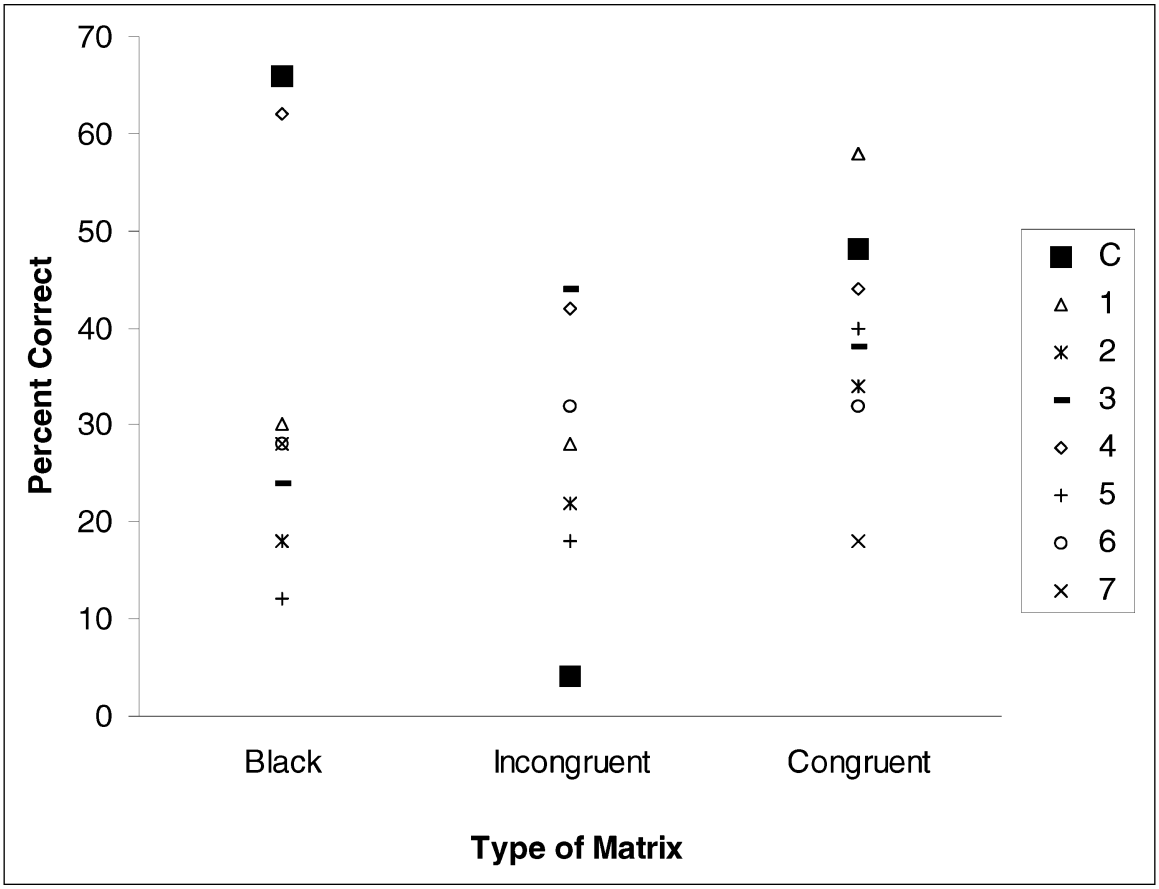

Fig. 1. Percentage of correct recall of each type of matrix for C and the 7 nonsynesthetes (1–7).

In this study, each participant was shown each matrix four times. To assess relatively long-term recall, we compared each participant's recall of the black digits following the fourth viewing of the black matrix on the 1st day of testing (i.e., 0-hr retention interval) with his or her recall of the black digits 2 days later (i.e., 48-hr retention interval). In the latter session, participants were not reshown the original black matrix. Rather, they were simply instructed to recall the black matrix they had seen 2 days earlier. Figure 2 shows each participant's percentage of correct recall of the black digits following the 0-hr and 48-hr retention intervals. It should be noted that by presenting the matrix of black digits four times in succession on the 1st day of testing, we were able to elevate the performance of 3 of the nonsynesthetes to match C's performance. Like C, these nonsynesthetes showed nearly 100% correct recall of the black digits following the fourth presentation of the matrix on the 1st day of testing. The most important finding (e.g., shown in Figure 2 is the contrast between C's performance and the nonsynesthetes' performance across the two retention intervals. Not surprisingly, for all 7 of the nonsynesthetes (including the 3 with nearly perfect recall at the 0-hr retention interval), there was a significant decrease in the recall of the digits across the two retention intervals, all $\chi^2(1, N = 100) > 10.00$, $p < .007$. In contrast, C's recall of the digits did not decrease across the two retention intervals, $\chi^2(1, N = 100) = 2.040$, $p > .10$.[3] These results are consistent with the earlier observation regarding C's memory for the sequences of digits presented to her as part of the class demonstration. The results provide yet another indication of C's extraordinary memory for digits relative to the memory of nonsynesthetes.

We believe that C had superior long-term recall of the black digits because the digits elicited strong synesthetic colors. However, it is possible that C's superior long-term recall of the black digits reflects an above-average general memory ability. To evaluate this possibility, we conducted a follow-up experiment in which we assessed C's long-term recall of stimuli that do not elicit strong synesthetic color experiences. Following the same procedures that we used when testing long-term recall of digits, C and 7 nonsynesthetes memorized and recalled matrices of 50 simple line-drawn shapes randomly chosen from a set of 10 exemplars (e.g., $\forall$, ∇, $\rightarrow$, $\approx$, ⊠, θ). Each participant's recall of a matrix of shapes was tested immediately following the fourth viewing of the matrix on the 1st day of testing (i.e., 0-hr retention interval) and again 2 days later (48-hr retention interval).

The results of this follow-up experiment are shown in Figure 3. The figure shows that C's recall of the shapes decreased across the two

3. Interestingly, even when C was tested 2 weeks later on the same matrix of digits, her performance remained nearly perfect.

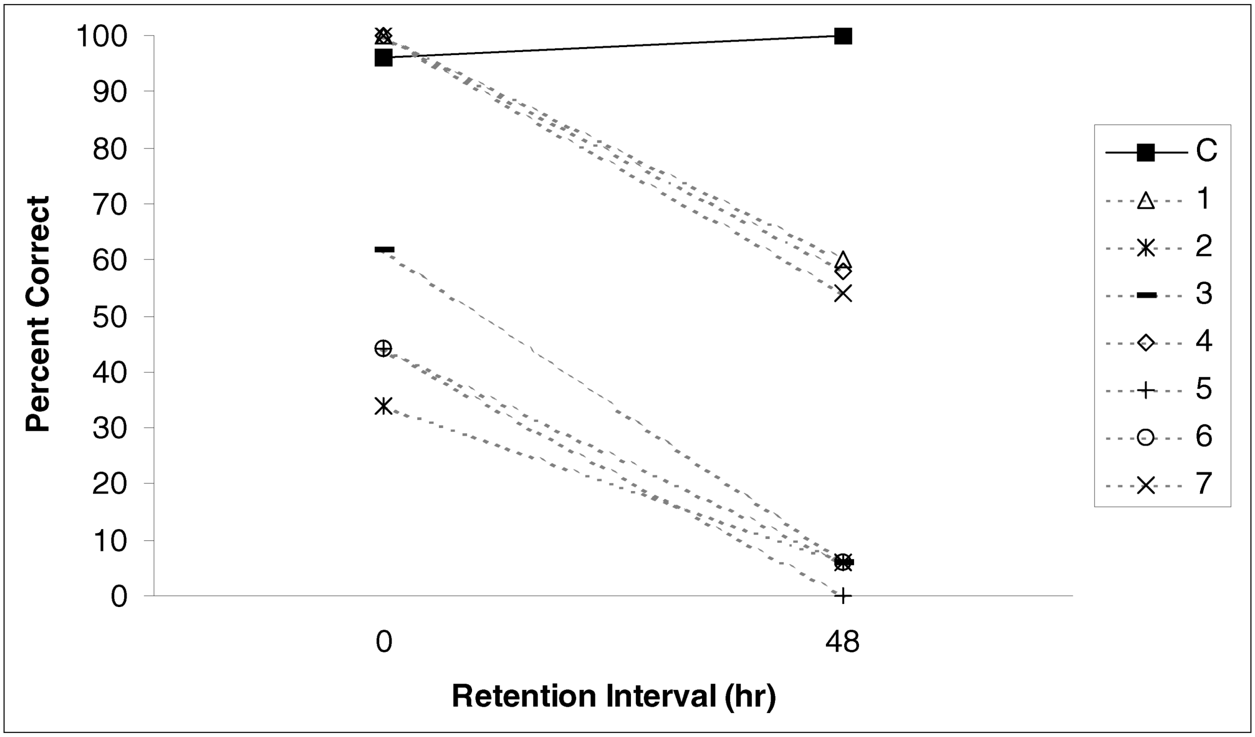

Fig. 2. Percentage of correct recall of the matrix of black digits following a 0-hr and a 48-hr retention interval for C and the 7 nonsynesthetes (1–7).

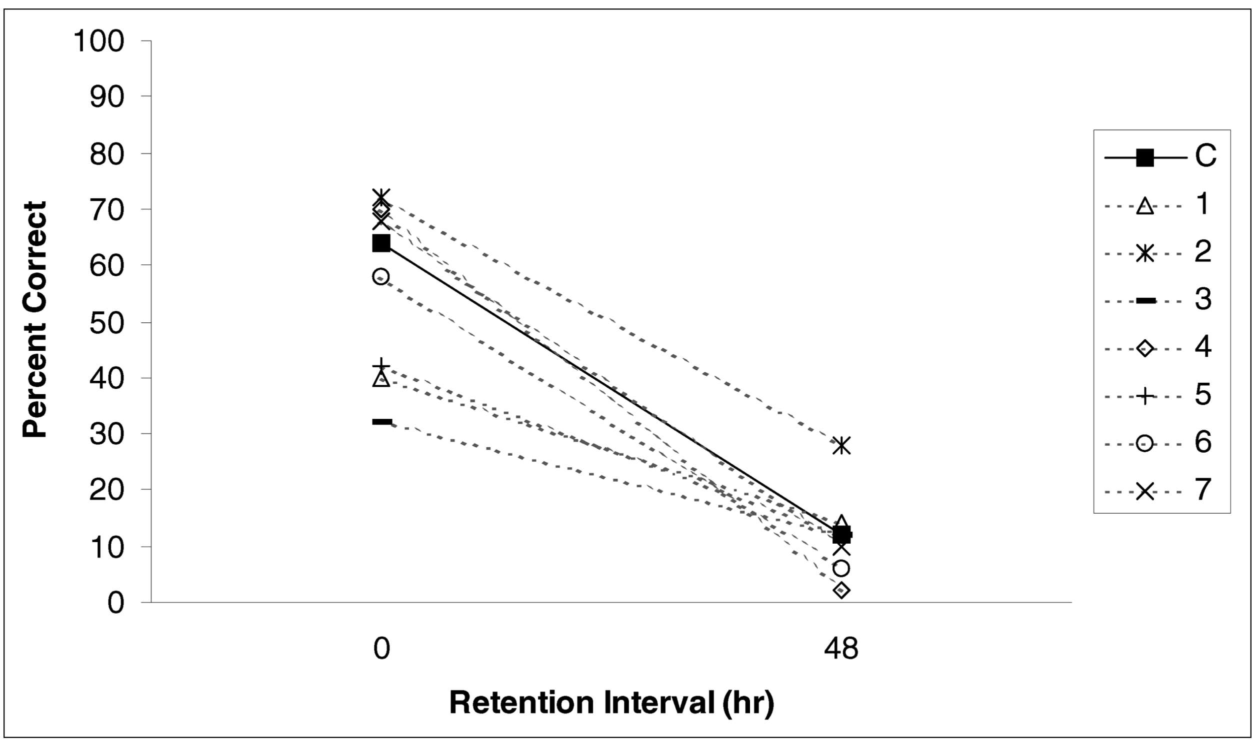

Fig. 3. Percentage of correct recall of the matrix of black shapes following a 0-hr and a 48-hr retention interval for C and the 7 nonsynesthetes (1–7).

retention intervals, $\chi^2(1, N = 100) = 28.7, p < .001$, and that the magnitude of this decrease (52%) was within the range of the decreases shown by the 7 nonsynesthetes (20%–68%). These results indicate that, unlike C's superior long-term recall of digits, which induce strong synesthetic color experiences, her long-term recall of shapes, which do not induce strong synesthetic color experiences, is no different from the long-term recall of nonsynesthetes. These findings provide considerable support for the idea that C's superior long-term recall of digits is due to her synesthesia rather than to an above-average general memory ability.

Taken together, the present findings demonstrate C's extraordinary memory for digits and show that her synesthetic color experiences play an integral role in her memory abilities. At this time, we can only speculate as to how C's synesthetic photisms influence her memory. C reports that when she is asked to remember black digits, she often simply remembers the synesthetic colors rather than the digits themselves. Somehow the synesthetic photisms may either increase the distinctiveness of the individual digits or create distinctive visual patterns that are considerably easier for C to remember than patterns of individual black digits. When digits are presented in incongruent colors, however, the incongruent colors interfere with her synesthetic photisms, and as a result her recall of the digits is dramatically reduced. Although it is currently unclear exactly how C's photisms influence her memory for digits, we nevertheless believe that the results of this study provide strong evidence supporting Luria's (1968) earlier suggestion that synesthetic experiences can have a direct influence on memory.

Acknowledgments—This research was made possible by research grants from the Natural Sciences and Engineering Research Council of Canada awarded to the second and fourth authors, as well as by a postgraduate scholarship from the Natural Sciences and Engineering Research Council of Canada awarded to the first author.

REFERENCES

Dixon, M.J., Smilek, D., Cudahy, C., & Merikle, P.M. (2000). Five plus two equals yellow. *Nature*, *406*, 365.

Ericsson, K.A., & Chase, W.G. (1982). Exceptional memory. *American Scientist*, *70*, 607–615.

Ericsson, K.A., Chase, W.G., & Faloon, S. (1980). Acquisition of memory skill. *Science*, *208*, 1181–1182.

Luria, A.R. (1968). *The mind of a mnemonist*. Cambridge, MA: Harvard University Press.

Mattingley, J.B., Rich, A.N., Yelland, G., & Bradshaw, J.L. (2001). Unconscious priming eliminates automatic binding of color and alphanumeric form in synaesthesia. *Nature*, *410*, 580–582.

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

Ramachandran, V.S., & Hubbard, E.M. (2001). Psychological investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society of London B*, *268*, 979–983.

Schneider, W. (1990). *MEL user's guide: Computer techniques for real-time experimentation*. Pittsburgh, PA: Psychological Software Tools.

Smilek, D., Dixon, M.J., Cudahy, C., & Merikle, P.M. (2001). Synaesthetic photisms influence visual perception. *Journal of Cognitive Neuroscience*, *13*, 930–936.

Smilek, D., Dixon, M.J., Cudahy, C., & Merikle, P.M. (2002). Concept driven color experiences in digit-color synaesthesia. *Brain and Cognition*, *48*, 570–573.

Wilding, J., & Valentine, E. (1997). *Superior memory*. Hove, England: Psychology Press.

(RECEIVED 6/30/01; REVISION ACCEPTED 12/18/01)