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Note

Training grapheme-colour associations produces a synaesthetic Stroop effect, but not a conditioned synaesthetic response

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ABSTRACT

The goal of this study was to investigate whether behavioural and physiological consequences of synaesthesia can be elicited by training specific letter-colour associations. Towards this goal 20 non-synaesthetic individuals were trained for 10 min on 7 consecutive days to associate four different letters with four specific colours. After training, we administered the synaesthetic Stroop test and the synaesthetic conditioning test. The results showed that a 1-week letter-colour association-training was sufficient to elicit a synaesthetic Stroop effect. In contrast, there was no evidence for a conditioned synaesthetic response as measured by skin conductance response in the synaesthetic conditioning test. These results indicate that the presence of a synaesthetic Stroop effect is not unique to true synaesthetes. We discuss methodological, experiential, and neuronal reasons for the dissociation between the synaesthetic Stroop test and the synaesthetic conditioning test.

1. Introduction

In synaesthesia, one attribute of a stimulus can lead to the experience of an additional attribute that is not physically present in that stimulus. In grapheme-colour synaesthesia, for example, viewing a particular black letter induces the experience of a specific colour. Imaging studies show that synaesthetic experiences are accompanied by greater activity in brain regions responsive to the particular concurrent (for colour, see Hubbard, Arman, Ramachandran, & Boynton, 2005; Nunn et al., 2002). Many studies have used Stroop-like tasks to demonstrate the true nature of synaesthesia and the purpose of this study was to test the discriminatory power of such tasks. Specifically, we tested whether behavioural and physiological consequences of synaesthesia can be elicited by training specific letter-colour associations.

In the synaesthetic Stroop test coloured letters are presented and participants have to name the colour of each letter. Some letters are in a colour congruent to the synaesthetic experience (e.g., a red "A" when the synaesthetic colour for "A" is red) and some are incongruent (e.g., a green "A" when the synaesthetic colour for "A" is red). Many studies have demonstrated that synaesthetes are slower in the incongruent compared to the congruent condition (Dixon, Smilek, Cudahy, & Merikle, 2000; Dixon, Smilek, & Merikle, 2004; Elias, Saucier, Hardie, & Sarty, 2003; Mattingley, Rich, Yelland, & Bradshaw, 2001; Mills, Boteler, & Oliver, 1999; Odgaard, Flowers, & Bradman, 1999; Ward, Li, Salih, & Sagiv, 2007; Wollen & Ruggiero, 1983). These results suggest that viewing a grapheme automatically elicits the experience of a synaesthetic colour and they may indicate that the synaesthetic Stroop test can be used as a diagnostic marker to identify true synaesthetes (e.g., Odgaard et al., 1999).

However, there are several hints that synaesthetic Stroop effects can occur purely by association and without the additional experience of the associated colour. For example, Elias et al. (2003) compared a synaesthete to an individual with well-learned semantic colour-digit associations from using cross-stitch patterns over a period of 8 years (e.g., the number 3 indicates the use of red thread and 7 indicates the use of yellow thread). The results revealed that both individuals showed the "synaesthetic" Stroop effect, indicating that this effect is not unique to synaesthetes. Similarly, Hancock (2006) presented a case study of a pair of twins with well learned colour-number associations, but not colour experiences. These associations were acquired from a coloured number jigsaw puzzle before age 3, when the associations were first noticed. When tested with the synaesthetic Stroop test at age 12, both boys showed a significant "synaesthetic" Stroop effect. Therefore, both studies (Elias et al., 2003; Hancock, 2006) demonstrate that individuals with perennial experience and well-learned associations show the same behavioural results in the synaesthetic Stroop test as do true synaesthetes.

So far, no study has investigated whether a briefer training would be sufficient to induce a synaesthetic Stroop effect in non-synaesthetes. In contrast, it has been suggested that training

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Table 1
Synaesthetic conditioning task: skin conductance response (SCR) in micro-Siemens for CS colour, CS letter, control colour stimuli and for the US.

Condition	Habituation		Conditioning	
	Mean	*SD*	Mean	*SD*
CS colour	.11	.11	.42	.46
CS letter	.09	.09	.18	.20
Control colour stimuli	.10	.09	.18	.15
US			1.89	1.33

CS = conditioned stimuli, US = unconditioned stimuli.

controls to associate graphemes is not feasible "because training would not simulate a synaesthete's lifetime of experience with grapheme-color pairings" (Dixon et al., 2004, p. 343). This claim is in line with two studies in which a control group of trained non-synaesthetes was included. Nunn et al. (2002) over-trained a group of non-synaesthetes to associate aurally presented words with specific colours on a single day. In contrast to synaesthetes who showed an elevated activity in the area V4/V8 in the temporal cortex, the trained controls showed no such activity in a subsequent functional magnetic resonance imaging (fMRI) session when imagining colours in response to spoken words. Cohen Kadosh et al. (2005) trained a group of non-synaesthetes to associate digits with specific background colours for 5 consecutive days. The goal of their study was to show that colours implicitly evoke numerical magnitudes in colour-grapheme synaesthetes, but not in non-synaesthetic participants. The results conformed to these expectations. To summarize, the results of these studies indicate that trained controls show a different pattern of brain activations for trained materials than synaesthetes (Nunn et al., 2002) and that training digit colour associations is not sufficient to induce bidirectional cross-activation (Cohen Kadosh et al., 2005). However, they do not address the question of whether extended experience is necessary for the occurrence of the synaesthetic Stroop effect (Elias et al., 2003; Hancock, 2006) or whether a brief training of grapheme-colour associations may be sufficient to induce the synaesthetic Stroop effect.

Accordingly, the first goal of the present study was to investigate this question. In a group of non-synaesthetes, we trained specific grapheme-colour associations across 1 week, with approximately 10 min of training each day. In a subsequent test session we administered the synaesthetic Stroop test and we expected to find a synaesthetic Stroop effect. The second goal was to investigate whether similar results would be found with the synaesthetic conditioning task (Meier & Rothen, 2007). In this task participants are presented with coloured displays across three different phases (i.e., habituation, conditioning, and extinction). In the conditioning phase one specific colour is followed immediately by a loud startling sound which served as the unconditioned stimulus. The critical comparison involves trials on which the sound was not present: trials with the conditioned colour only and trials on which the letter of the trained colour-letter association is presented. In a previous study we have demonstrated that synaesthetes, but not controls, showed a conditioned response to graphemes that elicited the conditioned synaesthetic colour (Meier & Rothen, 2007).

2. Methods

2.1. Participants

Twenty non-synaesthetes (13 female and 7 male, $M = 24$ years, $SD = 7.77$) participated in this study. They were first screened to ensure that none experienced synaesthetic perception. In addition, a test of consistency was administered for the letters *E* to *Z* of the alphabet, and for the numerals 0–9, before the first training session and after the final test using the procedure of Witthoft and Winawer (2006). Consistency for hue was $r = .18$, which is comparable to the control group ($r = .21$) in our previous study, but statistically different from the group of synaesthetes ($r = .94$; cf., Meier & Rothen, 2007). The experimental procedure was carried out according to the Declaration of Helsinki and informed consent was obtained from each of the participants before the first training session.

2.2. Materials and procedure

2.2.1. Training

Participants trained for approximately 10 min on 7 consecutive days to associate four particular letters with four specific colours. In the first session they were informed that the goal of the study was to learn specific letter-colour mappings. Specifically, they were instructed that "A" presented in red, "B" presented in green, "C" presented in yellow, and "D" presented in blue were considered as correct mappings. Before each training session the mapping information was repeated and participants were instructed to press as quickly and accurately as possible the designated "yes" and "no"-keys on the computer keyboard. In each training session 480 trials, 240 requiring a "yes"-response and 240 requiring a "no"-response, were presented randomly on a computer screen. For "yes"-responses each of the four letters was presented 60 times in the correct letter-colour mappings and for "no"-responses each of the letters was presented equally often in one of the other three colours. On a particular trial, a letter in Arial 200 point bold font was presented in the center of the screen against a white background until a response was made. Each stimulus covered a visual angle of about 4.5 degrees in width and 5.3 degrees in height. After a response the next trial was initiated. In order to enhance motivation, participants received cumulative feedback about accuracy and reaction time after each block.

2.2.2. Test

On the eighth day the synaesthetic conditioning task and the synaesthetic Stroop test, always presented in this order, were administered. Two counterbalancing versions were used in order to prevent carry over effects. One half of the participants were presented with the letter "A" in the synaesthetic conditioning task and with the letters "C" and "D" in the synaesthetic Stroop task, and the other half were presented with the letter "D" in the synaesthetic conditioning task and with the letters "A" and "B" in the synaesthetic Stroop task.

Skin conductance response (SCR) was sampled at 20 Hz with two electrodes, attached to the thenar and hypothenar eminences of the non-dominant hand. Participants were seated in a comfortable chair, 0.6 m in front of a computer screen. They were asked to relax, to remain silent, and to attend to the squares that would appear on the screen. Each square was shown for 2 s. A new square was not presented until the SCR was stable and the inter-stimulus-interval was between 10 and 20 s. In the habituation phase the five coloured squares (green, blue, yellow, red and white) were randomly presented 12 times for a total of 60 trials. The side of each square covered a visual angle of approximately 10.6 degrees. Depending on the counterbalancing condition, the white square included the letter "A" or "D" which had been associated with red and blue, respectively, during the association training. These letters were presented in a standard Arial 320 point font and each covered a visual angle of about 6.6 degrees in width and about 8.1 degrees in height. In the conditioning phase, a total of 28 squares were presented in a fixed pseudo-random order: seven squares (which were either blue or red, depending on the counterbalancing condition) were followed immediately by a startling sound (i.e., the unconditioned stimulus, US) of 1 s duration. Three white squares including either an A or a D (depending on the counterbalancing condition) were used as conditioned letter stimuli (CS letter) and three coloured squares (which were either red or blue, depending on the counterbalancing condition) were used as the conditioned colour stimuli (CS colour). None of the CS stimuli was followed by the US. An additional 15 squares which were green, yellow and either red or blue (conversely to the squares followed by the startling sound) and which were never followed by the startling sound were used as filler stimuli. The specific procedure for the condition with blue as the CS is depicted in Fig. 1. For the group with red as CS, blue and red squares were used contrariwise

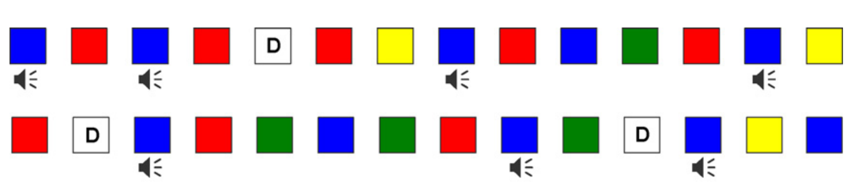

Fig. 1. Synaesthetic conditioning task: example of the conditioning phase (in the counterbalancing condition we presented the letter A instead of D, and the red colour instead of the blue colour was followed by the UCS). For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.

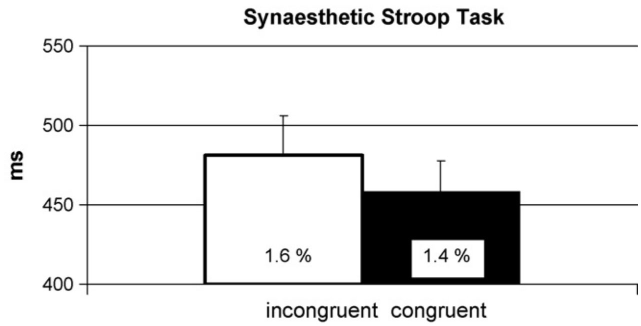

Fig. 2. Synaesthetic Stroop task: response times for congruent and incongruent trials (bars represent standard errors) and errors (percentage).

and the white square included an A instead of a D. In the extinction phase, two CS (blue or red) and two white squares (including the corresponding letter) were presented alternating twelve times for a total of 24 trials. These trials were included to extinguish the conditioned response and were not considered for the analysis.

Next, the synaesthetic Stroop task was administered. Participants were informed that coloured letters would be presented on the computer screen. In one counterbalancing condition (i.e., if the letter "A" was presented during the synaesthetic conditioning task) they were instructed to press the b-key for a blue stimulus and the n-key for a yellow stimulus. In the other counterbalancing condition (i.e., if the letter "D" was presented during the synaesthetic conditioning task) they were instructed to press the b-key for a green stimulus and the n-key for a red stimulus. For the former condition the letters "C" and "D" were used, and for the latter condition the letters "A" and "B" were used. By presenting the letters in the learned colour mappings a congruent condition was created and by presenting the letters in the reversed mappings an incongruent condition was created. A total of 40 trials were given, half of them were congruent and half of them were incongruent. Each trial consisted of a sequence of three displays: A fixation cross for 1500 ms, a letter displayed in black colour for 200 ms, and then changing to the colour that was either congruent or incongruent to the learned mapping. The latter stayed on the screen until a response was made (cf. Muggleton, Tsakanikos, Walsh, & Ward, 2007). Stimuli were presented in a standard Arial 30 point font and each covered a visual angle of about 1.3 degrees in width and about 1.5 degrees in height. After the conditioning task, participants were asked whether the presentation of a letter elicited a colour experience. None of them reported to experience the trained colour. However, all of them reported that the letters triggered the memory of the trained association.

3. Results

Association training. Accuracy was high from the beginning and was close to ceiling; across all sessions mean accuracy was $M = .98$ ($SD = .03$). Mean response times for the letter-colour mappings were 981 ms ($SD = 181$) on Day 1 and dropped to 605 ms ($SD = 72$) on Day 7. The response time data were modeled using a power function which explained 97.5% of the variance.

Synaesthetic stroop task.[1] Errors and mean reaction times are presented in Fig. 2. Separate mixed two-way analyses of variance (ANOVA) with counterbalancing condition ("A" and "B" vs. "C" and "D") as between-subjects factor and mapping (congruent vs. incongruent) as within-subjects factor were calculated for accuracy and response times. For accuracy, the ANOVA revealed no significant effect, all $F\text{s} < 1$. For response times the ANOVA revealed a main effect of mapping, $F(1,16) = 4.94$, $p < .05$; no other effect was significant, all $F\text{s} < 1$, indicating a "synaesthetic" Stroop effect which was 23 ms in magnitude.[2]

Synaesthetic conditioning task. For the analysis of the SCRs a data window of 5 s after each stimulus presentation was defined. The event-related SCR was calculated as the difference between the highest amplitude and the baseline in each data window (see Table 1). The critical comparison involved the SCRs elicited by the CS colour and the CS letter. A mixed three-factorial ANOVA with counterbalancing condition ("A" and red vs. "D" and blue) as between-subjects factor and CS-type (colour vs. letter) and phase (habituation vs. conditioning) as within-subjects factors revealed significant main effects of CS-type (with $F(1,18) = 11.4$, $p < .01$) and of phase ($F(1,18) = 11.7$, $p < .01$), as well as a significant interaction between CS-type and phase ($F(1,18) = 6.9$, $p < .05$). No other effect was significant (all $F\text{s} < 1$). Post hoc t-tests revealed that while SCRs for the CS colour trials did not differ during habituation, they were significantly higher for CS letter trials during conditioning, $t(19) = 3.1$, $p < .01$, indicating that coloured stimuli, but not the letter that was associated with the colour during training, elicited a conditioned response.[3]

4. General discussion

The first goal of this study was to investigate whether a short colour-letter association training of 10 min on 7 consecutive days would be sufficient to mimic a synaesthetic Stroop effect in non-synaesthetes. Our results indicate that this was the case. They extend previous findings of a synaesthetic Stroop effect in non-synaesthetes with much longer practice of letter-colour associations (Elias et al., 2003; Hancock, 2006). The trained non-synaesthetes in the present study reported that the letters triggered the memory of the trained association. However, none of them reported that the letters triggered a colour *experience*. Therefore, in line with Elias et al. (2003) we conclude that the synaesthetic Stroop test is very useful to assess the strength of a semantic association. However, it seems to fail to assess what is unique about synaesthesia, namely the experience of the synaesthetic colour.

The second goal was to investigate whether a synaesthetic conditioning effect would occur in trained non-synaesthetes. The results showed that although the participants acquired a conditioned startle reaction in response to a conditioned colour, there was no evidence that the letter that was associated with that particular colour during training also triggered a conditioned reaction. This result contrasts our previous findings with true synaesthetes who showed the synaesthetic conditioning effect and it also contrasts the findings from the synaesthetic Stroop test.

There are several explanations how this dissociation between the synaesthetic Stroop test and the synaesthetic conditioning task in trained non-synaesthetes may have occurred. First, methodological differences between the two tasks may be responsible. For example, it is possible that the Stroop test is a more reliable measure and it is obvious that it is more likely to find a statistical significance with a more reliable test (cf. Meier & Perrig, 2000). However, due to the fact that the skin conductance response for CS letter stimuli and for control stimuli was identical it is not likely that a power prob-

[1] Due to a technical error data of two participants were lost, with nine participants remaining in each counterbalancing condition.

[2] In order to ensure that the finding of a synaesthetic Stroop effect cannot be caused by the particular mappings (i.e., A and B coloured in red or green, respectively, and C and D coloured in yellow or blue, respectively), we tested a supplementary control group of 20 participants, recruited from the same population. We administered the same procedure of the synaesthetic Stroop task, but without previous training. Mean accuracy was $M = .98$, $SD = .04$ and mean response time was 477 ms (478.4 ms, $SD = 77.0$ for the congruent condition and 476.7 ms, $SD = 71.7$ for the incongruent condition). Separate mixed two-way ANOVAs with counterbalancing condition ("A" and "B" vs. "C" and "D") as between-subjects factor and mapping (congruent vs. incongruent) as within-subjects factor showed no differences, neither for accuracy nor for response times, and no interactions, all $F\text{s} < 1$.

[3] There was a slight numerical increase in SCR for the letter stimuli during conditioning. In order to test whether this increase was related to a general increase in arousal triggered by the occasional presentation of the US, the CS letter trials were compared to those colour trials that were never associated with the US (i.e., the control colour stimuli). An ANOVA with stimulus-type (control colour stimuli vs. CS letter) and phase (habituation vs. conditioning) as within-subject factors revealed a significant main effect for Phase $F(1,19) = 8.9$, $p < .01$. No other effect was significant (all $F\text{s} < 1$), indicating that the slight numerical increase for CS letter (and control colour stimuli) is due to a general increase in arousal in the conditioning phase that is not related to the specific CS letter stimuli.

lem was the source of the failure to find a synaesthetic conditioning effect. Another possibility is that the amount of training was not sufficient and that with more training a synaesthetic conditioning effect might have been found. To investigate this possibility further research is necessary. Similarly, it is possible that a different amount of association strength is required for the synaesthetic Stroop and the synaesthetic conditioning effect and that the amount of training administered in the present study was sufficient to induce the synaesthetic Stroop effect, but not the synaesthetic conditioning effect. Again, future research is necessary to rule out this possibility. Another explanation which may be compatible with the "amount of training" hypothesis is that a colour *experience* is necessary for the synaesthetic conditioning effect. It is possible that with longer training the experience of a colour in response to the presentation of a particular grapheme may be triggered. However, it is important to note that earlier attempts to induce synaesthetic colour experiences have failed (e.g., Howells, 1944; Kelly, 1934), and it is not clear whether it is possible at all to induce a synaesthetic experience even with more extensive training.

In our previous study with true synaesthetes we have discussed two potential explanations for the synaesthetic conditioning effect (Meier & Rothen, 2007). According to the first it may be simply a generalization of the conditioned response. After the conditioned response to the colour stimulus is established, the presentation of the grapheme triggers the associated synaesthetic colour and this is sufficient to elicit the conditioned response. Such a mechanism may also be operating in trained non-synaesthetes who have acquired semantic grapheme-colour associations. However, the results of the present study provide no support for this explanation because the trained non-synaesthetes failed to show the synaesthetic conditioning effect—although they had successfully acquired the semantic association necessary for the synaesthetic Stroop effect.

According to the second explanation, the synaesthetic conditioning effect may be due to an implicit association between the grapheme and the startle response. When the startle response is originally coupled with the colour the grapheme representation is also activated. While at the level of subjective experience activation of the colour is unidirectional from grapheme to colour, performance may be based on an implicit bidirectional cross-activation. This activation fired back when the grapheme was presented physically in true synaesthetes (Meier & Rothen, 2007), but not in trained non-synaesthetes (this study). Training grapheme-colour associations seemed not to be sufficient for establishing the implicit activation required for the synaesthetic conditioning effect and it is possible that this kind of activation cannot be induced by training at all.[4] This latter interpretation would be consistent with findings from Cohen Kadosh et al. (2005). While they found that colours implicitly evoked numerical magnitudes in true synaesthetes, trained non-synaesthetes did not show such an effect. Therefore, training grapheme-colour associations may not be sufficient to induce phenomena that rely on implicit bidirectional cross-activation between colours and graphemes. It is possible that the occurrence of such activations is dependent on the presence of different cortical connections in subjects with true synaesthesia. In fact, recent studies provide evidence for structural and sensory-perceptual differences between synaesthetes and non-synaesthetes (Rouw & Scholte, 2007; Barnett et al., 2008).

In addition, there are individual differences between synaesthetes with regard to the locus of their experience. There is evidence that these can affect cognitive performance, in particular the magnitude of the synaesthetic Stroop effect. Projector synaesthetes who experience colours in the outer world show a stronger synaesthetic Stroop effect (between 160 and 200 ms) compared to associators who experience them in their mind's eye (between 30 and 40 ms; e.g., Dixon et al., 2004; Ward et al., 2007). The size of the synaesthetic Stroop effect of trained non-synaesthetes was 38 ms (Elias et al., 2003), 25 ms (Hancock, 2006) and 23 ms in the present study. Therefore it seems that trained controls may reach the Stroop performance level of associators. For future research, it remains to be seen whether further training of non-synaesthetes results in stronger synaesthetic Stroop effects. Similarly, it will be interesting to test whether it is possible to induce a synaesthetic experience with more training and whether then a synaesthetic conditioning effect can be found.

[4] As noted above, an alternative interpretation is that with more training a stronger association would be established and as a consequence it may be possible that trained non-synaesthetes would also show a synaesthetic conditioning effect. To test this alternative interpretation further empirical work is necessary.

References

Barnett, K. J., Foxe, J. J., Molhom, S., Kelly, S. P., Shalgi, S., Mitchell, K. J., et al. (2008). Differences in early sensory-perceptual processing in synaesthesia: A visual evoked potential study. *Neuroimage*, *43*, 605–613.

Cohen Kadosh, R., Sagiv, N., Linden, D. E. J., Robertson, L. C., Elinger, G., & Henik, A. (2005). When blue is larger than red: Colors influence numerical cognition in synesthesia. *Journal of Cognitive Neuroscience*, *17*, 1766–1773.

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

Dixon, M. J., Smilek, D., & Merikle, P. M. (2004). Not all synaesthetes are created equal: Projector versus associator synaesthetes. *Cognitive Affective & Behavioral Neuroscience*, *4*, 335–343.

Elias, L. J., Saucier, D. M., Hardie, C., & Sarty, G. E. (2003). Dissociating semantic and perceptual components of synaesthesia: Behavioural and functional neuroanatomical investigations. *Cognitive Brain Research*, *16*, 232–237.

Hancock, P. (2006). Monocygotic twins' colour-number association: A case study. *Cortex*, *42*, 147–150.

Howells, T. H. (1944). The experimental development of color-tone synaesthesia. *Journal of Experimental Psychology*, *34*, 87–103.

Hubbard, E., Arman, A. C., Ramachandran, V. S., & Boynton, G. M. (2005). Individual differences among grapheme-color synesthetes: Brain-behavior correlations. *Neuron*, *45*, 975–985.

Kelly, E. L. (1934). An experimental attempt to produce artificial chromaesthesia by the technique of the conditioned response. *Journal of Experimental Psychology*, *17*, 315–341.

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

Meier, B., & Perrig, W. J. (2000). Low reliability in perceptual priming: Consequences for the interpretation of functional dissociations between explicit and implicit memory. *The Quarterly Journal of Experimental Psychology*, *53A*, 211–233.

Meier, B., & Rothen, N. (2007). When conditioned responses "fire back": Bidirectional cross-activation creates learning opportunities in synaesthesia. *Neuroscience*, *147*, 569–572.

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

Muggleton, L., Tsakanikos, E., Walsh, V., & Ward, J. (2007). Disruption of synaesthesia following TMS of the right posterior parietal cortex. *Neuropsychologia*, *45*, 1582–1585.

Nunn, J. A., Gregory, L. J., Brammer, M., Williams, S. C. R., Parslow, D. M., Morgan, M. J., et al. (2002). Functional magnetic resonance imaging of synesthesia: Activation of V4/V8 by spoken words. *Nature Neuroscience*, *5*, 371–375.

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*, 651–664.

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

Ward, J., Li, R., Salih, S., & Sagiv, N. (2007). Varieties of grapheme-colour synaesthesia: A new theory of phenomenological and behavioural differences. *Consciousness and Cognition*, *16*, 913–931.

Witthoft, N., & Winawer, J. (2006). Synesthetic colors determined by having colored refrigerator magnets in childhood. *Cortex*, *42*, 175–183.

Wollen, K. A., & Ruggiero, F. T. (1983). Coloured-letter synesthesia. *Journal of Mental Imagery*, *7*, 83–86.