Vision Research 51 (2011) 43–47

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Interactions between colour and synaesthetic colour: An effect of simultaneous colour contrast on synaesthetic colours

Tanja C.W. Nijboer *, Titia Gebuis, Susan F. te Pas, Maarten J. van der Smagt

Department of Experimental Psychology, Helmholtz Institute, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands

ARTICLE INFO

Article history:
Received 8 March 2010
Received in revised form 24 September 2010

Keywords:
Synaesthesia
Colour induction
Simultaneous colour contrast

ABSTRACT

We investigated whether simultaneous colour contrast affects the synaesthetic colour experience and normal colour percept in a similar manner. We simultaneously presented a target stimulus (i.e. grapheme) and a reference stimulus (i.e. hash). Either the grapheme or the hash was presented on a saturated background of the same or opposite colour category as the synaesthetic colour and the other stimulus on a grey background. In both conditions, grapheme-colour synaesthetes were asked to colour the hash in a colour similar to the synaesthetic colour of the grapheme. Controls that were pair-matched to the synaesthetes performed the same experiment, but for them, the grapheme was presented in the colour induced by the grapheme in synaesthetes. When graphemes were presented on a grey and the hash on a coloured background, a traditional simultaneous colour-contrast effect was found for controls as well as synaesthetes. When graphemes were presented on colour and the hash on grey, the controls again showed a traditional simultaneous colour-contrast effect, whereas the synaesthetes showed the opposite effect. Our results show that synaesthetic colour experiences differ from normal colour perception; both are susceptible to different surrounding colours, but not in a comparable manner.

1. Introduction

Synaesthesia is the phenomenon in which stimulation of one sensory (sub-) pathway (e.g. form) leads to an automatic, involuntary experience in a second sensory or cognitive pathway (e.g. colour). In an extensively studied form of synaesthesia, grapheme-colour synaesthesia, non-coloured graphemes (i.e. letters or digits) may be perceived as inherently coloured. In a variety of studies, the influence of this synaesthetic colour experience on the performance on several tasks been tested, both at a perceptual and a cognitive level. Examples range from experiments on visual search (e.g. Ramachandran & Hubbard, 2001) and perceptual grouping (Kim, Blake, & Palmeri, 2006) to Stroop-like interference (Cohen Kadosh & Henik, 2006; Johnson, Jepma, & de Jong, 2007), and priming effects (Gebuis, Nijboer, & van der Smagt, 2009a, 2009b; Mattingley, Rich, Yelland, & Bradshaw, 2001).

In fMRI studies, it has been found that cortical areas involved in normal colour processing (such as area V4, which has been linked to colour constancy (Walsh, 1999; Zeki & Marini, 1998)) are also activated during synaesthetic colour experiences (Hubbard, Arman, Ramachandran, & Boynton, 2005; Sperling, Prvulovic, Linden, Singer, & Stirn, 2006). This suggests that the synaesthetic colour experience and normal colour perception might share a common neural basis. In the current study, we aim to investigate whether the synaesthetic colour experience will be susceptible to the same influences as normal colour perception by examining the influence of *simultaneous colour contrast* (also known as colour induction)[1]. In normal colour processing, a grey patch presented on a red background is perceived as slightly greenish, whereas this same patch presented on a green background is perceived as slightly reddish. Here, it will be investigated whether coloured background have comparable influence on the perception of synaesthetic colour.

In most simultaneous contrast experiments, participants have to adjust and match the colour of a reference stimulus to the colour of a target stimulus. In the current study, the target stimulus was a grapheme that induced a synaesthetic colour and the reference was a hash mark that did not induce a synaesthetic experience. Two conditions were included in the current experiment: either the hash or the grapheme was presented on a coloured background (i.e. reference and target condition, respectively). In either case, synaesthetes had to adjust and match the synaesthetic colour of the grapheme onto the hash. In this manner, the influence of simultaneous colour contrast on both the formation/perception of the

---

* Corresponding author. Fax: +31 253 4511.
E-mail address: t.c.w.nijboer@uu.nl (T.C.W. Nijboer).

[1] In our view, chromatic induction can be seen as misdirected attempt to maintain colour constancy; the visual system erroneously attributes the change in wavelength distribution of the light to a difference in illumination instead of a difference in reflectance of the surrounding background. Colour constancy and chromatic induction can then be interpreted as manifestations of the same perceptual mechanism (Walraven et al., 1987; Valberg & Lange-Malecki, 1990).

0042-6989/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2010.09.030

synaesthetic colour (i.e. target condition) and the to-be matched hue (i.e. reference condition) were investigated in isolation.

2. Methods

2.1. Participants

Twelve synaesthetes (two projectors) participated in each condition, nine of which participated in both (mean age: 35, sd: 7). The consistencies over time of the synaesthetic colour experiences were tested on several occasions. Additionally, 24 controls (12 per condition) were also included (mean age: 32, sd: 13). All participants had normal or corrected-to-normal visual acuity and reported no colour blindness, which was confirmed by the Ishihara test for colour blindness (Ishihara, 1917).

2.2. Apparatus

All stimuli were generated on a Pentium class computer and presented on a calibrated, 21-inch monitor (75 Hz, 1024 × 768). The red, green, and blue phosphors were measured using a hand-held spot SLR tri-stimulus colorimeter (Konica Minolta, model CS-100A). In both conditions, participants viewed the monitor binocularly from a distance of 57 cm, which was controlled for with a chin and forehead rest.

2.3. Stimuli and procedure

First, the synaesthetes were asked to match the hue of their synaesthetic experience of an achromatic grapheme onto an achromatic hash (which did not induce a synaesthetic colour experience) by adjusting the RGB gun values. The grapheme was presented on the left side of the monitor and the hash on the right side. Both were presented on a grey background. Based on the matched colours, only those graphemes inducing a red, green, yellow and blue hue were selected for the experiment. The size of the stimuli was 1–2° of visual angle in width and 2.5° of visual angle in height.

In the experimental *reference* condition (see Fig. 1, upper left panel), the graphemes were presented on a grey background, whereas the hash was presented on a coloured background. The reference stimulus was presented once on a background of the same colour category as induced by the grapheme (e.g. on a red background for a grapheme that induced a reddish colour), and once on a background of a colour roughly on the opposite side of colour space (e.g. on a green background for a grapheme inducing a reddish colour). In the experimental *target* condition (see Fig. 1, upper right panel), the graphemes were presented on a coloured background, whereas the reference was presented on a grey background. All graphemes were presented once on a background of the same categorical colour (e.g. red inducing grapheme on a red background) and once on a background of the opposing colour (e.g. red inducing grapheme on a green background). The Luv values of the background were as follows: grey background: Luv = 80.6, 0.0, −0.0; red background: Luv = 48.1, 151.9, 34.5, green background: Luv = 87.8, −82.7, 106.1, yellow background: Luv = 95.3, 12.3, 104.1, blue background: Luv = 32.9, −8.4, −131.0. These background colours were chosen, as they represented the maximum saturation of the prototypical colour within the above colour categories, and therefore can be expected to exert the maximum simultaneous colour-contrast effect.

All participants were tested individually in a quiet, darkened room. Synaesthetes were instructed to match the colour of the reference stimulus on the right side of the screen to the synaesthetic colour experience of the grapheme on the left side. There was no time limit, and participants were allowed to adjust the colour as many times as they wanted, until they were satisfied with the result. Controls were presented with physically coloured graphemes in both conditions and asked to match the colour of the reference stimulus to the perceived colour of the grapheme. Controls were matched one-on-one to synaesthetes, ensuring that different results cannot be attributed to differences in colours used in both groups.

2.4. Analysis

All RGB values of the colour matches of the symbols were transformed to the Luv-colour space. Luv space was chosen to be able to equalise the perceptual distances between the colours. For both the target and the reference condition, the distance in colour space (delta E) between the matched colour (red, green, yellow and blue) and the actual midpoint (grey) in colour space was calculated (see Fig. 2 for an example). Per condition, delta E for each colour was statistically compared using Multivariate Repeated Measures with the colour (red, green, yellow and blue) and background (same, opposing) as *within-subject* variables and group (synaesthetes, controls) as *between-subject* variable.

3. Results

3.1. Reference condition (grapheme on grey)

A main effect of colour was found ($F(3, 63) = 21.49$, $p < .001$), demonstrating that the distance in colour space between the

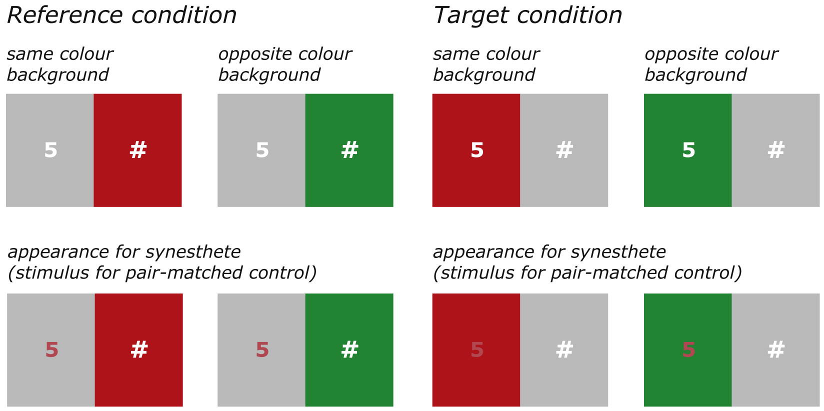

Fig. 1. Example of stimulus configuration. The left, upper panel shows the configuration for the reference condition, with the grapheme presented on a grey background and the reference stimulus either a same colour or an opposite-colour background. The right, upper panel shows the configuration for the target condition, with the graphemes presented on either a same colour, or an opposite-colour background, and the reference stimulus on a grey background. In the lower panels, the appearance for a synaesthete (and the stimulus for a pair-matched control) is shown.

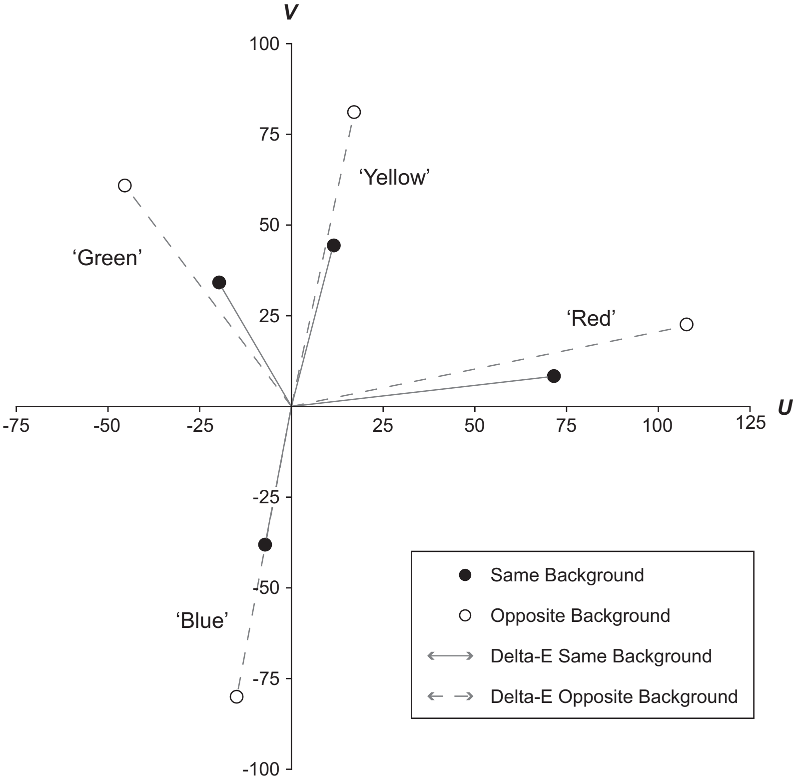

Fig. 2. Example of the results for the four colour conditions (target condition) for the control participants. Average *U*–*V* coordinates are shown for same-colour backgrounds (filled circles) and opposite-colour backgrounds (open circles). The length of the solid and dashed grey lines denotes the delta (per colour) for the same and opposite-colour background conditions respectively.

matched colours and the actual midpoint in colour space was different for the four colours used. Importantly, the distances between matched colour and the midpoint in colour space were comparable between synaesthetes and controls ($F(3, 63) = .68$, $p = .570$).

Additionally, a main effect of background was found ($F(1, 21) = 19.59$, $p < .001$), revealing that the overall distance between the matched colours and the actual midpoint in colour space was smaller when the reference was presented on an opposite compared to a similar colour background (see Fig. 3a). There was no interaction between background and group ($F(1, 21) = 1.70$, $p = .206$), illustrating that the shifts were comparable for synaesthetes and controls. This is not surprising, as one would expect the background colour to exert its influence on the hash it surrounds, not the grapheme (see Fig. 1).

Furthermore, neither interaction between colour and background nor a two-way interaction with group was obtained ($F(3, 63) = .23$, $p = .873$ and $F(3, 63) = 2.10$, $p = .111$ respectively), showing that the magnitude of the shifts on both opponent and same-colour backgrounds was comparable for each colour, and suggesting that the overall magnitude of the shifts was comparable between the synaesthetes and controls (see Fig. 3B).

3.2. Target condition (grapheme on colour)

A main effect of colour was found ($F(3, 63) = 22.22$, $p < .001$), demonstrating that the distance in colour space between the matched colours and the actual midpoint in colour space was again different for the four colours used. The distances between the point in colour space for matched colours and the midpoint in colour space were comparable between synaesthetes and controls ($F(3, 63) = 1.35$, $p = .265$).

Additionally, a main effect of background was found ($F(1, 21) = 27.60$, $p < .001$), revealing that the overall distance between the matched colours and the actual midpoint in colour space was larger when the grapheme was presented on an opposite compared to a similar colour background (see Fig. 4A). However, there was a significant interaction between background and group ($F(1, 21) = 193.69$, $p < .001$), illustrating the shifts in colour space were in the *opposite direction* for the synaesthetes compared to the controls (see Fig. 4B). This intriguing effect will be elaborated upon in the Discussion.

Finally, no interaction was found between colour and background ($F(3, 63) = 1.04$, $p = .384$), showing that the magnitude of the shifts for both opponent and same-colour backgrounds was comparable for each colour nor was a two-way interaction found with group ($F(3, 63) = .03$, $p = .994$).

4. Discussion

The aim of the current study was to investigate whether the synaesthetic colour experience would be susceptible to simultaneous colour-contrast effects in a comparable manner to normal colour perception. The rationale behind the aim was that V4, an area commonly found to be active during normal colour processing has been shown to be active during synaesthetic colour experiences (e.g. Hubbard et al., 2005; Nunn et al., 2002; Rouw & Scholte, 2007; Weiss, Zilles, & Fink, 2005). The degree of similarity between normal and synaesthetic colour perception was investigated by examining the influence of *simultaneous colour contrast*. Two conditions were included: either a hash or a grapheme was presented on a coloured background (i.e. reference and target condition, respectively). In either case, synaesthetes had to adjust and match the synaesthetic colour of the grapheme onto the hash. For controls,

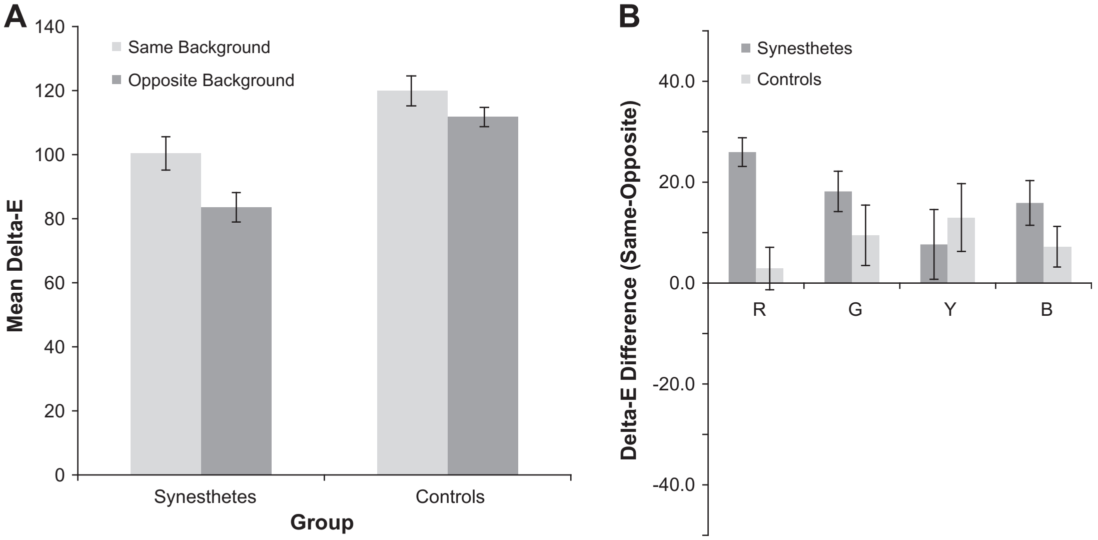

Fig. 3. (A) Mean delta E for reference stimuli presented on a background of the same and opposing colour (reference condition, i.e. grapheme on grey), split for synaesthetes and controls. (B) Differences between matched colours on same- and opposite-colour backgrounds (delta-E difference) for synaesthetes and controls, split per grapheme colour. Error bars represent standard errors of the mean.

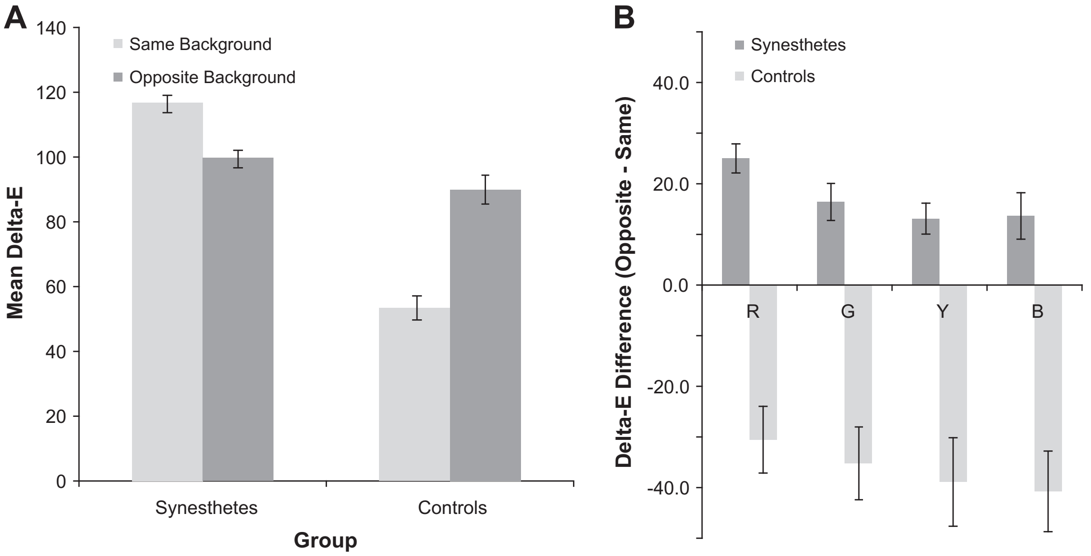

Fig. 4. (A) Mean delta E for reference stimuli when the grapheme was presented on a background of the same and opposing colour (i.e. target condition), split for synaesthetes and controls. (B) Differences between matched colours on same- and opposite-colour backgrounds (delta-E difference) for synaesthetes and controls split per grapheme colour. Error bars represent standard errors of the mean.

the graphemes were already coloured with the hues of their pair-matched synesthetes.

The results showed that in the *Reference condition*, the influence of simultaneous colour contrast on the to-be matched hue was comparable in direction and magnitude for synaesthetes and controls. The results for the *Target condition,* however, showed that the direction of the shifts in colour matching for the synaesthetes was *not* comparable to the direction of the shifts made by the controls; the shifts for the controls, but not for the synaesthetes followed the expectations for colour-contrast effects. Apparently, when a grapheme inducing a synaesthetic colour is presented on a coloured background, the synaesthetic colour experience does not follow the general ‘rules’ of simultaneous colour contrast, even though surrounding colour does influence the perceived synaesthetic hue.

We can only speculate on the mechanism for this counter-intuitive result. One possibility is that synaesthetic colour association is a particularly strong case of object-colour associations. As Hansen and colleagues have shown, object-colour associations can modulate colour appearance (Hansen, Olkkonen, Walter, & Gegenfurtner, 2006). They asked participants to adjust the colour of objects generally associated with a diagnostic colour (e.g. a banana), until they appeared achromatic. Generally, participants adjusted the colour in such a way that the shifts were in the direction opposite of the diagnostic colour (e.g. blue in the case of the banana) in order to be perceived a grey. Hansen et al. (2006) concluded that colour perception was significantly modulated by high-level visual memory. In other words, strong object-colour associations influence low-level visual perception. Such an object-colour association might be similar to the synaesthetic grapheme-colour association. In the *Reference condition,* the colour-contrast effects influence the perceived colour of the hash, a symbol not associated with any specific colour, hence normal colour-contrast effects were obtained. In the

Target condition, however, the colour-contrast effects directly influence the grapheme that is associated with a specific colour. In order to overcome the colour-contrast effects on the synaesthetic hue, more saturation of the colour is needed on the opposite-colour background (i.e. more 'red' is needed to get to the specific reddish hue of the five in. Fig. 1), and less saturated colour is needed on the same-colour background. Thus, the induced colour appearance of the achromatic grapheme together with the synaesthetic colour experience might be responsible for the matched colour in the reference stimulus.

An alternative explanation could be that synaesthetic colour perception is far more noisy than the perception of real colour perception. From a Bayesian point of view, this would mean that the synaesthetic colour percept would be far less reliable than the percept of the surrounding colour. In shape perception, such differences in reliability have shown to induce assimilation of the noisy target towards the clearly defined surround (van der Kooij & te Pas, 2009). The synaesthetic stimulus could thus have assimilated towards the surround colour in a similar manner.

In sum, our results show that the synaesthetic colour experience differs from normal colour perception. Synaesthetic as well as normal colours were found to be susceptible to different surrounding colours, but not in a comparable manner. Therefore we conclude that although synaesthetic colours appear to be as 'real' as real colours, synaesthetic colour processing is clearly different from 'real' colour processing. This concurs with the recent proposal that colour might only be part of the story as the experience of material properties might better capture the (diversity of) synaesthetic experiences (Eagleman & Goodale, 2009).

Acknowledgments

We would like to thank Sarah Plukaard to helping testing the participants and Edward de Haan for useful comments and discussions on earlier versions of the paper.

References

Cohen Kadosh, R., & Henik, A. (2006). Color congruity effect: Where do colors and numbers interact in synesthesia? *Cortex, 42*(2), 259–263.

Eagleman, D. M., & Goodale, M. A. (2009). Why color synesthesia involves more than color. *Trends in Cognitive Sciences, 13*(7), 288–292.

Gebuis, T., Nijboer, T. C., & van der Smagt, M. J. (2009a). Multiple dimensions in bi-directional synesthesia. *European Journal of Neuroscience, 29*(8), 1703–1710.

Gebuis, T., Nijboer, T. C., & van der Smagt, M. J. (2009b). Of colored numbers and numbered colors: Interactive processes in grapheme-color synesthesia. *Experimental Psychology, 56*(3), 180–187.

Hansen, T., Olkkonen, M., Walter, S., & Gegenfurtner, K. R. (2006). Memory modulates color appearance. *Nature Neuroscience, 9*(11), 1367–1368.

Hubbard, E. M., Arman, A. C., Ramachandran, V. S., & Boynton, G. M. (2005). Individual differences among grapheme-color synesthetes: Brain-behavior correlations. *Neuron, 45*(6), 975–985.

Ishihara, S. (1917). *Tests for colour-blindness*. Tokyo, Japan: Kanehara Shuppan Co., Ltd..

Johnson, A., Jepma, M., & de Jong, R. (2007). Colours sometimes count: Awareness and bidirectionality in grapheme-colour synaesthesia. *Quarterly Journal of Experimental Psychology (Colchester), 60*(10), 1406–1422.

Kim, C. Y., Blake, R., & Palmeri, T. J. (2006). Perceptual interaction between real and synesthetic colors. *Cortex, 42*(2), 195–203.

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*(6828), 580–582.

Nunn, J. A., Gregory, L. J., Brammer, M., Williams, S. C., 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*(4), 371–375.

Ramachandran, V. S., & Hubbard, E. M. (2001). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society: Biological Sciences, 268*(1470), 979–983.

Rouw, R., & Scholte, H. S. (2007). Increased structural connectivity in grapheme-color synesthesia. *Nature Neuroscience, 10*(6), 792–797.

Sperling, J. M., Prvulovic, D., Linden, D. E., Singer, W., & Stirn, A. (2006). Neuronal correlates of colour-graphemic synaesthesia: A fMRI study. *Cortex, 42*(2), 295–303.

Valberg, A., & Lange-Malecki, B. (1990). Colour constancy in mondrian patterns: A partial cancellation of physical chromaticity shifts by simultaneous contrast. *Vision Research, 30*, 371–380.

van der Kooij, K., & te Pas, S. F. (2009). Uncertainty reveals surround modulation of shape. *Journal of Vision, 9*(3), 1–8 (15).

Walraven, J., Benzschawel, T. L., & Rogowitz, B. E. (1987). Color-constancy interpretation of chromatic induction. *Die Farbe, 34*, 269–273.

Walsh, V. (1999). How does the cortex construct color? *Proceedings of the National Academy of Sciences of the United States of America, 96*(24), 13594–13596.

Weiss, P. H., Zilles, K., & Fink, G. R. (2005). When visual perception causes feeling: Enhanced cross-modal processing in grapheme-color synesthesia. *Neuroimage, 28*(4), 859–868.

Zeki, S., & Marini, L. (1998). Three cortical stages of colour processing in the human brain. *Brain, 121*(Pt 9), 1669–1685.