

Short Report

# Synaesthesia is associated with enhanced, self-rated visual imagery

Kylie J. Barnett <sup>a,b,c</sup>, Fiona N. Newell <sup>a,b,\*</sup>

<sup>a</sup> School of Psychology, Trinity College, Dublin, Ireland

<sup>b</sup> Institute of Neuroscience, Trinity College, Dublin, Ireland

<sup>c</sup> Smurfit Institute of Genetics, Trinity College, Lloyd Building, Dublin 2, Ireland

Received 14 March 2007

Available online 12 July 2007

---

## Abstract

Although the condition known as synaesthesia is currently undergoing a scientific resurgence, to date the literature has largely focused on the heterogeneous nature of synaesthesia across individuals. In order to provide a better understanding of synaesthesia, however, general characteristics need to be investigated. Synaesthetic experiences are often described as occurring ‘internally’ or in the ‘mind’s eye’, which is remarkably similar to how we would describe our experience of visual mental imagery. We assessed the role of visual imagery in synaesthesia by sampling a large group of synaesthetes and found that they report experiencing more vivid mental images than controls. These findings have important implications for our general understanding of synaesthesia and, in particular, emphasize the need to control for visual imagery in behavioural and neuroimaging paradigms.

© 2007 Elsevier Inc. All rights reserved.

*Keywords:* Synaesthesia; Visual imagery; VVIQ

---

## 1. Introduction

In 1880 Sir Francis Galton claimed to be occupied in eliciting the “degree and manner in which different persons possess the power of seeing images in the mind’s eye” (Galton, 1880, p.252). He described a number of individuals who perceived numerals in elaborate spatial arrangement and reported some ‘curious’ cases of colour associations with numerals, noting the apparent heredity of such traits and the fact that the capacity was present from childhood. While Galton (1880) discussed these abilities with reference to visual imagery, over 120 years later, we now refer to these phenomena by the term ‘synaesthesia’. Synaesthetes experience a sensory ‘mixing’, whereby a stimulus presented to one sensory modality elicits an illusory sensory-perceptual experience in another (Cytowic, 2002). The nature of synaesthetic experiences makes it likely that they share the neural substrates involved in normal perception and mental imagery. Earlier studies of synaesthesia exam-

---

\* Corresponding author. Address: Institute of Neuroscience, Trinity College, Dublin, Ireland. Fax: +353 (0) 1 6712006.  
E-mail address: [fiona.newell@tcd.ie](mailto:fiona.newell@tcd.ie) (F.N. Newell).

ined trends in inducer-concurrent associations (Marks, 1975; McKellar, 1957) but while there has been a resurgence of scientific interest in synaesthesia (for a review see Rich & Mattingley, 2002), the role that visual imagery might play in mediating such experiences has received little attention.

In terms of their phenomenology, synaesthetic experiences have much in common with mental imagery. First, visual mental imagery has been described as the ability to form ‘mental pictures’, or to ‘see in the mind’s eye’ (Marks, 1973) and, similarly, many synaesthetes describe their experiences as internal, occurring in the ‘minds eye’ or ‘inside one’s head’ (Baron-Cohen, Wyke, & Binnie, 1987; Dixon, Smilek, & Merikle, 2004; Grossenbacher, 1997). Furthermore, these conscious experiences occur in the absence of related external, sensory stimulation. For example, a colour can be either induced (as in synaesthesia) or imaged in the absence of stimulation of sensory colour receptors. Second, mental imagery is often reported as sufficient to induce a synaesthetic experience. In other words, simply imagining an inducer (e.g. the letter ‘A’) is sufficient to evoke the same concurrent as the physical inducer itself (Dixon, Smilek, Cudahy, & Merikle, 2000). Finally, synaesthetic inducers are often modality independent. For example, in its most common form, linguistic–colour synaesthesia (Barnett et al., *in press*; Cytowic, 2002; Rich, Bradshaw, & Mattingley, 2005), linguistic stimuli induce colour experiences when they are presented in either their orthographic/written, spoken or tactile (e.g. Newell, Kilroy, & Chan, *in preparation*) form. Since the concurrents are common to inducers from different modalities, this strongly suggests that linguistic information is either represented in a modality-independent manner or that it is recoded into a single modality that, in turn, triggers the synaesthetic experience. Ramachandran and Hubbard (2001) have argued that linguistic–colour synaesthesia arises in the grapheme area of the visual cortex which lies adjacent to V4, the area involved in colour information processing. If linguistic information from other modalities is recoded into vision then it is possible that mental imagery may mediate this recoding (e.g. Lederman, Klatzky, Chataway, & Summers, 1990; Sathian & Zangaladze, 2001; Zhang, Weisser, Stilla, Prather, & Sathian, 2004) and trigger common, crossmodal synaesthetic experiences.

Given the similarities between synaesthesia and mental imagery, and the potential role of imagery in synaesthesia, it is surprising that an investigation of general imagery ability in synaesthetes has not hitherto been conducted. It may be, for example, that synaesthesia is related to a general ability to imagine stimuli. If this were the case then we might expect that synaesthetes report experiencing more vivid mental images than non-synaesthetes. On the other hand, general imagery abilities may be unrelated to synaesthesia but instead enhanced mental imagery may be more specifically related to the set of stimuli that induce or are evoked through synaesthesia.

Although the role of imagery in synaesthesia has generally been overlooked in the literature (but see Ramachandran, Hubbard, & Butcher, 2004), several neuroimaging studies have investigated whether common neural substrates underpin perceived, imagined and synaesthetic colours. It might be expected, for example, that colours induced in linguistic–colour synaesthesia activate the same neural regions that process the perception of colour, namely area V4, and indeed this has been reported (Hubbard, Arman, Ramachandran, & Boynton, 2005; Nunn et al., 2002; Sperling, Prvulovic, Linden, Singer, & Stirn, 2005; Steven, Hansen, & Blakemore, 2005). In fact, both imagined and synaesthetic colours are associated with activation in cortical regions such as V4 that are also known to be involved in perception (Aleman, Rutten, Sitskoorn, Dautzenberg, & Ramsey, 2001; Kosslyn, Thompson, Kim, & Alpert, 1995; Nunn et al., 2002). However, a recent study has suggested that imagined and synaesthetic colours can activate different neural substrates. Rich et al. (2006) found that area V4 was activated in synaesthetes and non-synaesthete controls in response to *both* externally presented colour Mondrians and imagined colour. However, unlike previous reports, they found that synaesthetic colours selectively activated the left medial lingual gyrus, an area previously implicated in colour knowledge (Chao & Martin, 1999). Interestingly, Rich et al. (2006) did not report a difference in V4 activation in synaesthetes compared to controls during the colour imagery task, although their small sample size ( $n = 7$ ) makes it difficult to make inferences about the absence of activation (see e.g. Thirion et al., 2007). However, what is not clear from the above studies is whether or not imagery ability is different across synaesthete and non-synaesthete groups and whether any such difference may underlie differential activation in brain areas associated with induced or imagined stimuli.

To investigate mental imagery ability in synaesthetes, we surveyed visual imagery in a large sample of naïve synaesthetes using the Vividness of Mental Imagery Questionnaire (VVIQ) (Marks, 1973) and compared their reported imagery ability to a control group of unrelated, age-matched participants. Given that there is a

strong familial component to synaesthesia (i.e. between 40% and 50% of synaesthetes report having at least one relative who is also a synaesthete), we also decided to collect data from non-synaesthete first-degree relatives to compare their imagery ability to their synaesthete relatives. The high familial rate of synaesthesia suggests a genetic component (Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996; Rich et al., 2005), therefore if synaesthesia and imagery are related we might expect the same pattern of vividness of imagery in relatives as in the synaesthetes themselves. Although eidetic imagery scores are more highly correlated in monozygotic than dizygotic twins (Smith & Lund, 1949), the heritability of imagery ability is not well documented.

## 2. Method

### 2.1. Participants

We obtained data from 38 synaesthetes, 22 first-degree relatives and 38 age-matched controls. The synaesthetes responded to advertisements placed in the national media and their relatives subsequently volunteered to partake in our study. Our age-matched controls were recruited from staff and students based in Trinity College Dublin. Our protocol was approved by the School of Psychology Ethics Committee, Trinity College Dublin and all participants gave written informed consent to participate. Table 1 shows the number of males and females in each group and mean and SD of the ages for each group.

### 2.2. Materials

The VVIQ is a subjective questionnaire made up of 16 items (see Marks, 1973). Participants are required to fill in the VVIQ twice, once with eyes open and once with eyes closed, thus, 3 scores related to vividness of mental imagery are yielded from this questionnaire: one each for eyes open, eyes closed, and total VVIQ score (i.e. the sum of eyes open and eyes closed conditions).

### 2.3. Procedure

Prior to the study, all synaesthetes were first required to report the nature of their synaesthesia and provide details of their inducer-concurrent pairings. They were subsequently retested between 3 and 12 months afterwards on the consistency of their reported synaesthesia (see Barnett et al. for further details) in accordance with previous studies (Baron-Cohen & Harrison, 1997; Cytowic, 2002). A consistency score was calculated for each participant using the criteria outlined by Rich et al. (2005). Relatives and unrelated control participants were all screened for synaesthesia in advance of the study to ensure that they did not experience synaesthesia and none reported having synaesthetic experiences. Two of the first-degree relatives did not return this screening questionnaire but we were assured by the synaesthetes that these relatives were not synaesthetes.

Synaesthetes were subsequently posted three copies of the VVIQ and were asked to fill in one questionnaire and to have at least one non-synaesthete first-degree relative (i.e. parents, siblings and offspring) fill in the other(s). We asked synaesthetes and their relatives not to discuss their scores until they had completed the questionnaire. The VVIQ questionnaire was also distributed amongst the unrelated control group.

Table 1  
Number of females and males and mean/SD age in years in each group (synaesthetes, relatives, controls)

	Group		
	Synaesthetes	Relatives	Controls
Number of females	35	12	26
Number of males	3	10	12
Mean age (years) <sup>a</sup>	50.3	50.7	43.6
SD age (years)	16.9	17.0	14.7

<sup>a</sup> The three groups did not differ significantly for age ( $\chi^2(2) = 3.542, p = .170$ ).

### 3. Results

The large female-to-male ratio of around 11:1 in our synaesthete group (see Table 1) is in accordance with previous reports of a marked sex-bias in synaesthesia (Baron-Cohen et al., 1996; Rich et al., 2005), however it is not consistent with a recent study by Simner et al. (2006) who found a 1:1 ratio in a randomly sampled group. The average consistency score for synaesthetes was 92% ( $SD = 11.4$ ). This percentage is comparable to previous reports (Rich et al., 2005; Ward & Simner, 2005). The majority of synaesthetes in this sample (34 from a total of 38) experience some form of linguistic–colour synaesthesia. Reports of coloured music only or synaesthetic concurrents in association with a non-lexical inducer such as taste were rare (2 synaesthetes per type). The majority in this sample (27 from a total of 38) also reported experiencing concurrents in the ‘minds eye’ and 36 synaesthetes reported that concurrents could be elicited by simply imagining an inducer (e.g. a grapheme).

The total scores on the VVIQ for each of the groups are as follows (with lower VVIQ scores corresponding to the subjective report of more vivid mental imagery); synaesthetes (65.1), non-synaesthete relatives (72.4) and unrelated non-synaesthete controls (74.4) (see Fig. 1). Mann–Whitney tests were used to assess pairwise

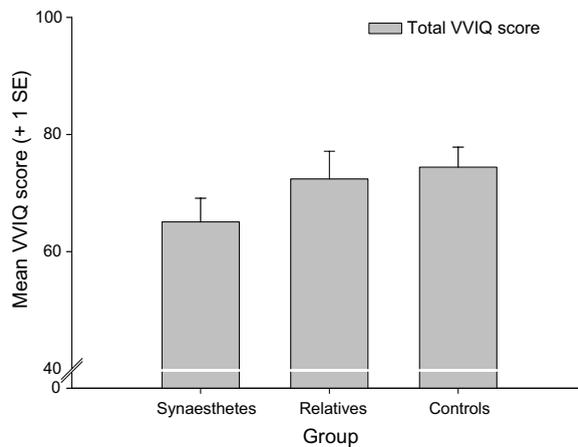


Fig. 1. Mean VVIQ scores plus one SE of the mean plotted for synaesthetes, relatives and controls. Note: lower VVIQ scores indicate subjective report of more vivid mental images.

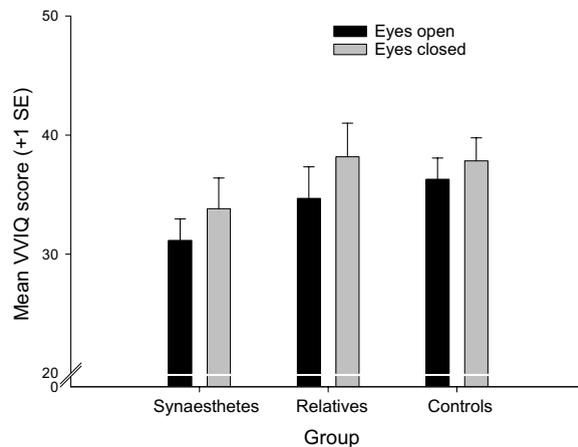


Fig. 2. Mean VVIQ scores plus one SE of the mean for eyes open and eyes closed conditions plotted for synaesthetes and controls. Note: lower VVIQ scores indicate subjective report of more vivid mental images.

differences between controls and synaesthetes, synaesthetes and relatives and controls and relatives<sup>1</sup>. Synaesthetes had the lowest overall VVIQ scores (i.e. they rated their visual mental images as the most vivid). Synaesthetes' scores were significantly lower than those of the age-matched controls ( $U = -2.094$ ,  $p = .036$ ), although they did not differ from their relatives' scores ( $U = -1.512$ ,  $p = .131$ ). Overall VVIQ scores did not differ between controls and relatives ( $U = -.453$ ,  $p = .651$ ).

Mean VVIQ scores in the 'eyes open' and 'eyes closed' condition for each group are plotted in Fig. 2. In the 'eyes open' condition, synaesthetes had significantly lower VVIQ scores than controls ( $U = -2.162$ ,  $p = .031$ ) although they did not differ from their relatives ( $U = -1.136$ ,  $p = .256$ ). There were also no differences between controls and relatives in this condition ( $U = -.499$ ,  $p = .618$ ). In the 'eyes closed' condition, there was a non-significant trend for synaesthetes to have lower VVIQ scores than controls ( $U = -1.726$ ,  $p = .084$ ). However, there was no difference between the scores of synaesthetes and their relatives ( $U = -1.543$ ,  $p = .123$ ) or between controls and relatives in this condition ( $U = -.192$ ,  $p = .848$ ).

Finally, we compared the overall VVIQ scores between males and females (regardless of group) in order to assess for any effect of sex on imagery. Although our female participants achieved lower VVIQ scores ( $M = 68.5$ ,  $SD = 22.6$ ) than the male participants ( $M = 75.8$ ,  $SD = 23.6$ ), the difference was not significant ( $U = -1.500$ ,  $p = .134$ ).

#### 4. Discussion

To date the role of mental imagery in synaesthesia has been relatively unexplored. In order to detail the general characteristics of synaesthesia, we sampled a large population of synaesthetes and report an association between synaesthesia and the experience of vivid mental images. Our current findings suggest that enhanced visual imagery may be a trait common to synaesthetes and that Galton (1880) was correct to collectively discuss the traits we now term synaesthesia in conjunction with the superior ability to visualize in the 'mind's eye'.

There are now a number of studies indicating a familial genetic component to synaesthesia (Barnett et al., in press; Baron-Cohen et al., 1996; Rich et al., 2005; Ward & Simner, 2005). Although, in the current study it was only possible to recruit a relatively small number of relatives, it is interesting to note that while synaesthetes and controls differ in self-reported imagery abilities, first-degree relatives of synaesthetes do not differ from the performance of either synaesthetes or controls. There are several possible explanations for this result. First, it is likely that the effect is simply due to a lack of power in our data due to the limited number of relatives we could recruit in our sample. Second, it is possible that synaesthetes and their relatives discuss visual imagery which, in turn, may influence the way relatives rate their visual images. Finally, and although we have not provided any evidence for this, there remains the more interesting possibility that the mechanism responsible for vivid imagery may manifest itself as synaesthesia in some individuals. The generality of phenotypic-traits synaesthetes and their relatives is certainly worthy of further investigation.

The number of male synaesthetes in our sample was small ( $n = 3$ ), however we report no difference in VVIQ scores between males and females (regardless of group). There is some evidence to suggest that women are better imagers than men (Campos & Pérez, 1988; Richardson, 1999), however this is not consistent and our findings are in accordance with previous studies which report no difference between the sexes in vividness of visual imagery (McKelvie, 1995) or in self-reported control of mental images (Campos, Pérez-Fabello, & Gómez-Juncal, 2004).

In the current study synaesthetes report experiencing vivid mental images to stimuli in general, however we do not suggest that synaesthesia is simply the by-product of an overactive imagination. Mental imagery and the qualitative experiences of synaesthesia differ in marked ways. For example, visual images reproduce the world 'inside our heads', whereas synaesthetes experience both the real percept (i.e. a letter) and its induced colour simultaneously. Imagery is elaborate, non-consistent, flexible and subject to change. In contrast, the defining characteristic of synaesthesia is consistency of inducer-concurrent pairings over a life-time (Cytowic,

<sup>1</sup> We ran a Shapiro–Wilkes test of normality on the data. Control ( $p = .190$ ) and relative data ( $p = .457$ ) were normally distributed, the synaesthesia data was not ( $p = .006$ ). To avoid distribution assumptions we used non-parametric tests (Mann–Whitney; Kruskal–Wallis) to compare the three groups in the each condition: overall VVIQ score, VVIQ 'eyes open' and VVIQ 'eyes closed'.

1997). Mental images are detailed, pictorial and are not limited to particular categories of visual stimuli, while in contrast the detail of synaesthetic concurrents usually extends only to hue and texture (Baron-Cohen & Harrison, 1997). Unlike mental imagery, which is flexible and bi-directional, synaesthesia is (usually) unidirectional. For example; while ‘J’ might elicit red, a red strawberry does not elicit ‘J’. Linguistic–colour synaesthetes can reportedly distinguish between induced and imagined colours, the latter of which may be brighter (Steven & Blakemore, 2004). Finally, it has been reported that the two processes are dissociable at the neural level (Rich et al., 2006).

The fact that synaesthetes report more vivid mental images than controls has important implications. A recent fMRI study found that non-synaesthetes who report experiencing vivid visual images (as measured by the VVIQ) show an increase in activation in the visual cortex when performing an objective visualization task (Cui, Jeter, Yang, Montague, & Eagleman, 2007). Synaesthetes do not often report that their induced colours interfere with normal vision, although interference effects can be demonstrated using modified Stroop tasks as reported by Mattingley, Rich, Yelland, and Bradshaw (2001) and, likewise, we do not confuse visual mental images with true vision. However, our findings suggest that imagery may be a confound in many studies of synaesthesia, particularly neuroimaging studies. Moreover, this is most likely to be true in studies where synaesthetes are required to keep their eyes open or when synaesthetes are blindfolded and inducers are presented via the auditory modality (Aleman et al., 2001; Paulesu et al., 1995). Indeed, when synaesthetes have been presented with inducers via the auditory modality, the pattern of activation reported is not unlike that observed in mental imagery (Paulesu et al., 1995). Second, differences in vividness of mental imagery may be the basis for inconsistent findings in the literature regarding the neural correlates of real, imagined and synaesthetic colours. For example, Rich et al. (2006) found that cortical area V4 was activated in both synaesthetes and non-synaesthetes in response to imagined colour but only the left lingual gyrus was activated in response to induced colour in synaesthetes. This is in contrast to previous studies that report V4/V8 activation when synaesthetes experience colour following exposure to inducers presented through the auditory or visual modality (Hubbard et al., 2005; Nunn et al., 2002; Sperling et al., 2005; Steven et al., 2005). Furthermore, others have reported that visual imagery of colour in non-synaesthetes does not always activate regions involved in the veridical perception of colour (i.e. V4/V8), although again sample sizes were relatively small making the absence of an activation difficult to interpret (e.g. Howard et al., 1998; Nunn et al., 2002). These findings strongly suggest that the role of early visual areas in both imagery and synaesthesia remains open for debate (see Kosslyn & Thompson, 2003 for an overview of methodological factors that affect neuroimaging studies of mental imagery).

In summary, we assessed a large group of synaesthetes and find that they report more vivid mental images than an age-matched control group. There is a reasonable amount of evidence showing that subjective measures of visual imagery have behavioural and neural correlates (Amedi, Malach, & Pascual-Leone, 2005; Blajenkova, Kozhevnikov, & Motes, 2006; Cui et al., 2007; Marks & Isaac, 1995; Weatherly, Ball, & Stacks, 1997), and is likely that visual imagery is not a single ability, but rather a collection of abilities (Kosslyn, 1980). While the current findings do suggest further experimental investigation, they also emphasise a need to control for imagery in neuroimaging paradigms in order to quantify the degree of overlap between the perception of surface colour, visual imagery, and synaesthetic concurrents. Further research is needed to assess the role that imagery might play in modulating top-down processes, such as attention and meaning in synaesthesia and the extent to which cortical colour regions involved in perception and imagery (i.e. V4/V8) contribute to synaesthesia. This may not be easy given that the differences between perception and imagery, and the recruitment of early versus later regions of associative cortex in imagery are still debated (Mellet, Petit, Mazouyer, Denis, & Tzourio, 1998).

## References

- Aleman, A., Rutten, G. J. M., Sitskoorn, M. M., Dautzenberg, G., & Ramsey, N. F. (2001). Activation of striate cortex in the absence of visual stimulation: An fMRI study of synesthesia. *NeuroReport*, *12*, 2827–2830.
- Amedi, A., Malach, R., & Pascual-Leone, A. (2005). Negative BOLD differentiates visual imagery and perception. *Neuron*, *48*, 859–872.
- Barnett, K.J., Finucane, C., Asher, J., Bargary, G., Corvin, A.P., Newell, F.N., & Mitchell K.J. (in press). Familial patterns and the origins of individual differences in synaesthesia. *Cognition*.

- Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., & Bolton, P. (1996). Synaesthesia: Prevalence and familiarity. *Perception*, *25*, 1073–1080.
- Baron-Cohen, S., & Harrison, J. (1997). *Synaesthesia: Classic and contemporary readings*. Malden, MA: Blackwell Publishers.
- Baron-Cohen, S., Wyke, M. A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception*, *16*, 761–767.
- Blajenkova, O., Kozhevnikov, M., & Motes, M. A. (2006). Object-spatial imagery: A new self-report imagery questionnaire. *Applied Cognitive Psychology*, *20*, 239–263.
- Campos, A., & Pérez, M. J. (1988). Vividness of movement imagery questionnaire: relations with other measures of mental imagery. *Perceptual and Motor Skills*, *67*, 607–610.
- Campos, A., Pérez-Fabello, M. J., & Gómez-Juncal, R. (2004). Gender and age differences in measured and self-perceived imaging capacity. *Personality & Individual Differences*, *37*, 1383–1389.
- Chao, L. L., & Martin, A. (1999). Cortical regions associated with perceiving, naming, and knowing about colors. *Journal of Cognitive Neuroscience*, *77*, 25–35.
- Cui, X., Jeter, C. B., Yang, D., Montague, P. R., & Eagleman, D. M. (2007). Vividness of mental imagery: Individual variability can be measured objectively. *Vision Research*, *47*, 474–478.
- Cytowic, R. E. (1997). Synaesthesia: Phenomenology and neuropsychology – a review of current knowledge. In S. Baron-Cohen & J. E. Harrison (Eds.), *Synaesthesia: Classic and contemporary readings*.
- Cytowic, R. E. (2002). *Synaesthesia: A union of the senses*. Cambridge, MA: MIT Press.
- Dixon, M. J., Smilek, D., Cudahy, C., & Merikle, P. M. (2000). Five plus two equals yellow: Mental arithmetic in people with synaesthesia is not coloured by visual experience. *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.
- Galton, F. (1880). Visualised numerals. *Nature*, 252–256.
- Grossenbacher, P. G. (1997). Perception and sensory information in synaesthetic experience. In S. Baron-Cohen & J. E. Harrison (Eds.), *Synaesthesia: Classic and contemporary readings* (pp. 148–172). Malden, MA: Blackwell Publishers.
- Howard, R. J., ffytche, D. H., Barnes, J., McKeefry, D., Ha, Y., Woodruff, P. W., et al. (1998). The functional anatomy of imagining and perceiving colour. *NeuroReport*, *9*, 1019–1023.
- Hubbard, E. M., Arman, A. C., Ramachandran, V. S., & Boynton, G. M. (2005). Individual differences among grapheme-color synesthetes: Brain-behavior correlations. *Neuron*, *45*, 975–984.
- Kosslyn, S. M. (1980). *Image and mind*. Cambridge, MA: Harvard University Press.
- Kosslyn, S. M., & Thompson, W. L. (2003). When is early visual cortex activated during visual mental imagery? *Psychological Bulletin*, *129*(5), 723–746.
- Kosslyn, S. M., Thompson, W. L., Kim, I. J., & Alpert, N. M. (1995). Topographical representations of mental images in primary visual cortex. *Nature*, *378*, 496–498.
- Lederman, S. J., Klatzky, R. L., Chataway, C., & Summers, C. D. (1990). Visual mediation and the haptic recognition of two-dimensional pictures of common objects. *Perception & Psychophysics*, *47*(1), 54–64.
- Marks, D. F. (1973). Visual imagery differences in the recall of pictures. *British Journal of Psychology*, *64*, 17–24.
- Marks, L. E. (1975). On colour hearing synaesthesia: cross-modal translations of sensory dimensions. *Psychological Bulletin*, *82*, 303–331.
- Marks, D. F., & Isaac, A. R. (1995). Topographical distribution of EEG activity accompanying visual and motor imagery in vivid and non-vivid imagers. *British Journal of Psychology*, *86*, 271–282.
- 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.
- McKellar, P. (1957). *Imagination and thinking*. London: Cohen & West.
- McKelvie, S. J. (1995). *Vividness of Visual Imagery: Measurement, nature, function & dynamics*. New York: Brandon House.
- Mellet, E., Petit, L., Mazoyer, B., Denis, M., & Tzourio, N. (1998). Review: Reopening the mental imagery debate: lessons from functional anatomy. *NeuroImage*, *8*, 129–139.
- Newell, F.N., Kilroy, D., & Chan, J.S. (in preparation). Modality-independent induction of synaesthesia: evidence from tactile letter perception.
- Nunn, J. A., Gregory, L. J., Brammer, M., Williams, S. C. R., Parslow, D. M., Morgan, M. J., et al. (2002). Functional magnetic imaging of synaesthesia: Activation of V4/V8 by spoken words. *Nature Neuroscience*, *5*, 371–375.
- Paulesu, E., Harrison, J., Baron-Cohen, S., Watson, J. D. G., Goldstein, L. H., Heather, J., et al. (1995). The physiology of coloured hearing: A PET activation study of colour-word synaesthesia. *Brain*, *118*, 661–676.
- Ramachandran, V. S., & Hubbard, E. M. (2001). Psychophysical investigations into the neural basis of synaesthesia. *Proceedings of the Royal Society: Biological Sciences*, *268*, 979–983.
- Ramachandran, V., Hubbard, E. M., & Butcher, P. A. (2004). Synaesthesia, cross-activation, and the foundations of neuroepistemology. In G. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processes* (pp. 867–883). Cambridge: MIT Press.
- Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2005). A systematic, large scale study of synaesthesia: implications for the role of early experience in lexical-colour associations. *Cognition*, *98*, 53–84.
- Rich, A. N., & Mattingley, J. B. (2002). Anomalous perception in synaesthesia: A cognitive neuroscience perspective. *Nature Reviews Neuroscience*, *3*, 43–52.
- Rich, A. N., Williams, M. A., Puce, A., Syngeniotis, A., Howard, M. A., McGlone, F., et al. (2006). Neural correlates of imagined and synaesthetic colours. *Neuropsychologia*, *44*, 2918–2925.

- Richardson, J. T. E. (1999). *Imagery*. England: Psychology Press limited.
- Sathian, K., & Zangaladze, A. (2001). Feeling with the mind's eye: The role of visual imagery in tactile perception. *Optometry and Vision Science*, 8(5), 276–281.
- 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.
- Smith, G., & Lund, U. (1949). *Psychological studies in twin differences; with reference to afterimage and eidetic phenomena as well as more general personality characteristics*. England: Oxford Press.
- Sperling, J. M., Prvulovic, D., Linden, D. E. J., Singer, W., & Stirn, A. (2005). Neuronal correlates of colour-graphemic synaesthesia: An fMRI study. *Cortex*, 42, 295–303.
- Steven, M. S., & Blakemore, C. (2004). Visual synaesthesia in the blind. *Perception*, 33, 855–868.
- Steven, M. S., Hansen, P. C., & Blakemore, C. (2005). Activation of color-selective areas of the visual cortex in a blind synesthete. *Cortex*, 42, 304–308.
- Thirion, B., Pinel, P., Meriaux, S., Roche, A., Dehaene, S., & Poline, J. B. (2007). Analysis of a large fMRI cohort: Statistical and methodological issues for group analyses. *NeuroImage*, 25(1), 105–120.
- Ward, J., & Simner, J. (2005). Is synaesthesia an X-linked dominant trait with lethality in males? *Perception*, 34, 611–623.
- Weatherly, D. C., Ball, S. E., & Stacks, J. R. (1997). Reliance on visual imagery and its relation to mental rotation. *Perception and Motor Skills*, 52, 431–434.
- Zhang, M., Weisser, V. D., Stilla, R., Prather, S. C., & Sathian, K. (2004). Multisensory cortical processing of object shape and its relation to mental imagery. *Cognitive, Affective, & Behavioral Neuroscience*, 4, 251–259.