ACTIVATION OF COLOR-SELECTIVE AREAS OF THE VISUAL CORTEX IN A BLIND SYNESTHETE

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Abstract

Many areas of the visual cortex are activated when blind people are stimulated naturally through other sensory modalities (e.g., haptically; Sadato et al., 1996). While this extraneous activation of visual areas via other senses in normal blind people might have functional value (Kauffman et al., 2002; Lessard et al., 1998), it does not lead to conscious visual experiences. On the other hand, electrical stimulation of the primary visual cortex in the blind does produce illusory visual phosphenes (Brindley and Lewin, 1968). Here we provide the first evidence that high-level visual areas not only retain their specificity for particular visual characteristics in people who have been blind for long periods, but that activation of these areas can lead to visual sensations. We used fMRI to demonstrate activity in visual cortical areas specifically related to illusory colored and spatially located visual percepts in a synesthetic man who has been completely blind for 10 years. No such differential activations were seen in late-blind or sighted non-synesthetic controls; neither were these areas activated during color-imagery in the late-blind synesthete, implying that this subject's synesthesia is truly a perceptual experience.

Key words: synesthesia, V4/V8, supramarginal gyrus, angular gyrus, blind, color processing

Introduction

The first known reference to synesthesia is a description of a blind man who described the color scarlet as being "like the sound of a trumpet" (Locke, 1690). In the following centuries, there have been sporadic reports of individual late-blind visual synesthetes, including blind subjects who experienced colored-pitch (Phillipe, 1893), colored-vowel sounds (Galton, 1883), colored-spoken letters, colored words (especially for names), colored music (Starr, 1893), colored-olfaction (Cutsforth, 1925) and colored-Braille (Steven and Blakemore, 2004). These reports provide strong evidence for the notion that synesthesia can persist following blindness and that synesthesia therefore does not require continual associative learning or stimulation in the referred modality in order to be maintained (Steven and Blakemore, 2004).

Due to the behavioral focus of these studies (and the relatively recent emergence of neuroimaging) however, it remains unknown where in the brain is the activity that underlies visual synesthesia in blind subjects, whose visual cortices are no longer stimulated by real visual information. This is of special interest given what *is* known about processing capabilities of the visual cortex following blindness and its tendency to "re-map" to aid in the processing of tactile (Sadato et al., 1996), auditory (Weeks et al., 2000) and even language information (Amedi et al., 2003). Does the visual cortex also continue to generate activity that gives rise to synesthetic color? Specifically, does visual synesthesia (e.g., colored-hearing) in the blind activate those areas that were previously involved in the processing of real color, including area V4/V8, which is known to be activated during colored-hearing in sighted synesthetic individuals (Nunn et al., 2002)?

To investigate this, as part of a study of visual synesthesia in the blind (Steven and Blakemore, 2004), we used fMRI to determine the neural activations associated with the synesthetic visual experiences of a late-blind synesthete with colored-hearing.

Case Report

JF (right-handed male, 52) suffers from retinitis pigmentosa, which has caused retinal degeneration, with gradually deteriorating vision, which led to complete loss even of basic color sensation 10 years ago. JF has experienced visual synesthesia (in which particular forms of natural stimulation of either the auditory or tactile modality cause idiosyncratic visual color perception) from at least 5 years of age (i.e., since before losing his sight). For instance, JF experiences a form of colored-hearing in which he sees specific colored and spatially located visual percepts when he hears "time-words" (i.e., days of the week or months of the year). Unprompted tests on more than 40 synesthetic stimuli, two months apart, revealed extraordinary consistency of JF's verbal descriptions of his synesthetic colors (97.6%), which strongly suggests that his synesthesia is genuine (Steven and Blakemore, 2004).

TABLE I

List of the time-words spoken to JF, which evoked synesthetic colors, and the abstract non-time words, matched for frequency of usage in the English language (Kucera and Francis, 1967), which did not. All numbers are reported out of a maximum frequency of 69991. The controls heard the same time- and non-time words as did JF, but did not have synesthetic experiences for either category of words.

Time-word	Frequency of time-word usage	Matched word	Frequency of matched word usage
Monday	68	Excellent	68
Tuesday	59	Notice	59
Wednesday	35	Prepare	35
Thursday	34	Protect	34
Friday	60	Stories	60
Saturday	68	Wonder	68
Sunday	102	Becomes	102
January	53	Contrary	53
February	45	Expenditures	45
March	121	Heavy	121
April	73	Master	73
May	1399	Like	1339
June	103	Rates	103
July	66	While	66
August	53	Examples	53
September	60	Learning	60
October	54	Owned	54
November	75	League	75
December	53	Unusual	63

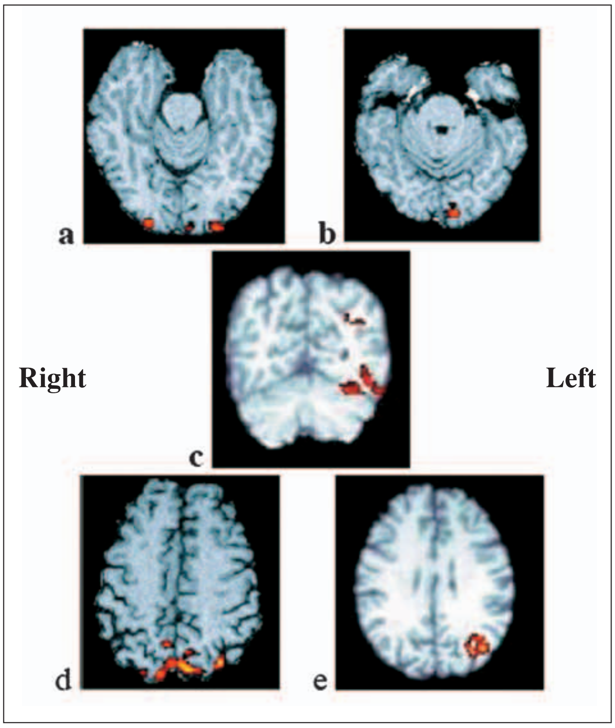

Fig. 1 – *Neural activations in response to time-words (vs. non-time words) in the late-blind synesthetic subject, JF. Horizontal sections are shown in radiological convention – left side on the right – with regions of interest in red-yellow. (a) axial plane z = 8. Bilateral BA 18: – 26, – 98, 8 and 24, – 98, 8; left BA17 is located between. (b) axial plane z = – 4. Left BA 17 (striate cortex): – 14, – 93, – 4. (c) coronal plane: y = – 64. Activations: left V4/V8 (BA19) – 30, – 66 – 20, left BA19 – 42 – 66 – 14, left angular/supramarginal gyri: – 40, – 70 30. (d) axial plane z = 64. Bilateral superior parietal lobule BA 7: – 8, – 56, 64 and 10, – 60, 64. (e) axial plane: z = 28. Left angular/supramarginal gyri – 40, – 70, 30. All coordinates are reported in standard MNI space (Evans et al., 1992).*

To determine which areas of JF's brain might be involved in the generation of his illusory colored percepts, we conducted an fMRI study. A pseudo-random block design paradigm was used to investigate three conditions. The first condition consisted of JF listening to "time-words" (see Table I), each of which evoked the impression of a colored "rectangular blob", spatially localized at a distinct position in the "visual field" of JF's mind's eye. During the second condition, JF listened to abstract words that were matched for frequency of usage to the time-words (Kucera and Francis, 1967) but which did not evoke synesthetic percepts (e.g., 'notice' and 'prepare'; see Table I). Each block in each condition consisted of listening to 12 time-words or 12 non-time-related words spoken for 24 seconds, with 18 seconds of rest (the third condition) separating the blocks. There were 24 blocks in total for each condition. Within the blocks for condition one and two, the subject performed a one-back matching task to ensure that he maintained attention constantly. Subtraction of the cortical activation measured during performance of condition two (listening to non-time words) from the cortical activation measured during performance of condition one (listening to time-words) was expected to reveal only activity related to the synesthetic impressions.

FMRI images were acquired using a Siemens Sonata 1.5T MRI machine with an interleaved multislice gradient echo EPI sequence. Each volume consisted of 35 contiguous axial slices collected from the whole brain, with an in-plane resolution of 3 × 3 mm and a slice thickness of 3 mm, covering the whole brain (matrix = 64 × 64, TR = 3 sec, TE = 50 msec). Analysis was performed using the freely available FMRIB Software Library 5.1 [Functional Magnetic Resonance Imaging of the Brain (FMRIB) Centre; Oxford, UK] with the following standard pre-processing steps: motion correction, spatial smoothing (FWHM = 3 mm), mean-based intensity normalization and nonlinear high-pass temporal filtering (sigma = 45 s). Statistical analysis used FILM, by fitting a 2-event general linear model and applying a local autocorrelation correction. Statistical (Z) maps were thresholded at $Z > 2.3$, with a corrected cluster extent threshold of $p < .01$.

Listening to time-words, which evoked spatially localized synesthetic colors for JF, specifically activated regions of his visual cortex, including both "early" areas (left Brodmann area – BA17 – or striate cortex – Figures 1a and 1b – and bilateral BA18 – Figure 1a), as well as more anterior extrastriate regions (left area V4 and left area V8; Figure 1c). Bilateral superior parietal lobule was also activated (Figure 1d), as was the inferior parietal lobule, which contains both the angular and supramarginal gyri (the activation spread throughout both gyri) (Figures 1c and 1e).

No difference in activity was observed in a non-synesthetic late-blind control, who was