

fMRI Study of Sound-color Synesthesia

J. Wang¹, M. Robinson-Long², K. Thompson³, P. J. Eslinger^{2,4}, and C. Lemley⁵

¹Radiology, Penn State University College of Medicine, Hershey, PA, United States, ²Neurology, Penn State University College of Medicine, Hershey, PA, United States, ³Biology, Elizabethtown College, Elizabethtown, PA, United States, ⁴Neural and Behavioral Sciences, Penn State University College of Medicine, Hershey, PA, United States, ⁵Psychology, Elizabethtown College, Elizabethtown, PA, United States

Introduction: Synesthesia is a condition that stimulation of one sensory modality will automatically trigger another un-stimulated perception modality. The estimated prevalence of synesthesia may be as high as 1 in 20. The most common two forms of synesthesia are: sound-color synesthesia and grapheme-color synesthesia. Behavioral studies indicate that synesthetes are consistent across time in their color photisms. Although common neurophysiological mechanisms may exist, different neural mechanisms have been proposed for different synesthesia. Functional brain imaging (PET and fMRI) has been used to study the underlying neural mechanisms of synesthesia. Recently, several studies on grapheme-color synesthesia and word-color synesthesia were published, even though there is some inconsistency in the neural substrates involved in those photisms, e.g., color center [1-4]. To our knowledge, there has been no report of fMRI studies on sound-color synesthesia since the noise from MR gradient system can trigger color photisms.

Methods: Two right-handed volunteers (one 45 yo male and one 22 yo female) with sound-color synesthesia participated in this study after giving written consent. They were physically healthy with no neurological impairments. Both of them have sound-color synesthesia since early childhood with no family history. In the test and retest of their color photisms on a package of different sounds, their color responses were highly consistent. During fMRI, visual and audio stimuli were presented to the participant through VisuaStim Digital Glasses and head-phone and participants' response was recorded through a handheld device. Before the fMRI, the subjects were trained on a computer to get familiar with the stimulation paradigms and the response device out of the magnet.

fMRI protocol: Every subject received the functional MRI twice. The first time was on a Bruker Biospac 3T system with a TEM head coil for RF transmission and reception; and second time was after 10 to 20 weeks on a Siemens Magnetom Trio 3T system with a 12-channel head coil for reception. T₁- and T₂-weighted images were acquired to exclude any potential neuroanatomic abnormalities. Functional images were acquired with T₂*-weighted EPI sequences (TR / TE = 3000 ms / 35 ms, flip angle = 90°, FOV = 23 × 23 cm², 24 5-mm-thick axial slices with no gap between slices, acquisition matrix = 64 × 64, number of average = 1). First, a twenty-block boxcar paradigm was used to locate the color center. Each experimental block consisted of visual slides of colorful patterns, lasting 18 secs, each colorful pattern represented for 3 secs. The baseline blocks each lasted 18 secs and consisted of the same patterns but void of color with only black and white contrast. The sound-color paradigm was presented when the goggles were power off. It included 10 experimental blocks and 10 baseline blocks. Each experimental block consisted of sound clips that were a mix of single tones (e.g., piano notes), musical compositions (e.g., song clips), and voices (e.g., news broadcasting clips). All of these sound clips would trigger specific color photisms to the two subjects. Each experimental block lasted 21 secs, consisting of 7 sound clips, each presented for 3 secs. Subjects were instructed and trained to respond to each clip by pressing the right button if they had a visual response of color to a sound, or the left button if they did not have a visual response of color to the sound. The baseline blocks each lasted 27 secs and consisted of silence and the subjects were instructed to do number counting and not to attend to the sound of the MRI scanner. In the second run in the Siemens system, the subjects were instructed to ignore the number counting instructions.

Data Processing: fMRI data were normalized to the Montreal Neurological Institute brain template [5] in a resolution of 2 × 2 × 2 mm³ and smoothed with a Gaussian kernel of 8 × 8 × 8 mm³ (FWHM). Statistic parametric maps were generated using general linear model with SPM2 [6].

Results: The two subjects' color center was activated and located by the real color paradigm (Fig. 1) even though the subjects reported color photisms from the scanner noise. The two subjects all responded to the sound clips with color photisms. They also reported that the scanner noise in the two different MR systems triggered different color photisms. When the male subject did number counting during baseline, he reported much less color photism. The sound-color paradigm triggered the male subject's color center, angular gyrus and superior parietal lobe activation, which was stronger when he was distracted from scanner noise by doing number counting (Fig. 2). Angular gyrus is known to involve in the visual cognition and language processing. Superior parietal lobe is known to be associated with multi-modal perception and processing. The female subject reported the scanner noise consistently gave her color photism. The sound-color paradigm only revealed weak activation in her left angular gyrus in the first run with number counting during baseline period.

Conclusion: Here we reported the first fMRI study on sound-color synesthesia. The result shows that color center, angular gyrus and superior parietal cortex are involved in some sound-color photisms. Background noise control is critical in the study of sound-color synesthesia using fMRI. Our observation suggests that there may be different levels or subcategories of sound-color synesthesia and attention distraction may be an effective method for defining subcategories of this kind of synesthesia.

References:

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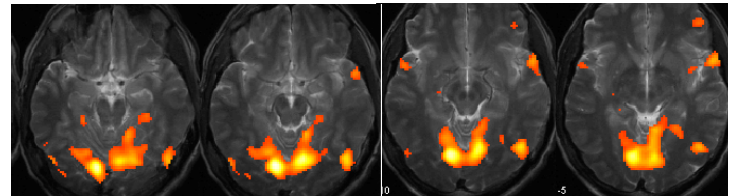


Figure 1. The color center activation responding to real color stimulation from a 45 yo man with sound-color synesthesia (family wise error corrected, $p < .05$).

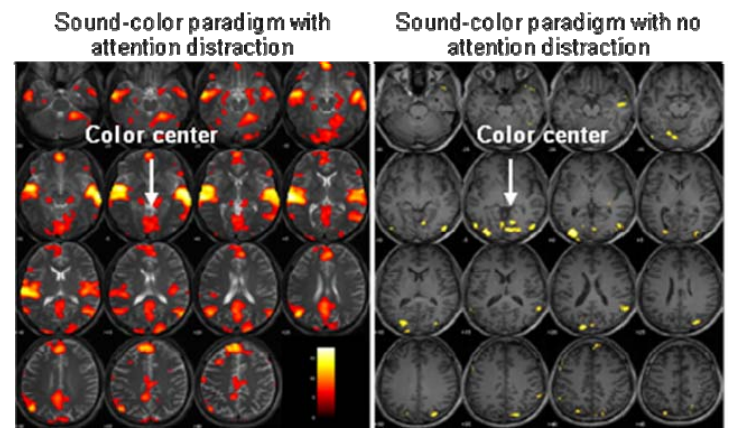


Figure 2. Sound clips triggered color center activation in a 45 yo man with sound-color synesthesia (left: 1st run, family wise error corrected, $p < .05$; right: 2nd run 20 weeks later, not corrected, $p < .001$).