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Neuroscientists Locate 'Imaginary' Colors

UCSD/Salk Team Gains Insight into Neural Basis of Perception, Finds Evidence of Cross-Activation in Brain Regions of People Who See Letters and Numbers in Colors

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Inga Kiderra

To most people a "red-letter day" is merely a metaphor. But it's everyday reality to a synesthete who sees the alphabet in colors.

Synesthesia, a condition characterized by one sensory experience generating another - so that shapes have tastes, for instance - is estimated to affect between 1 in 200 to 1 in 2,000 people. The most common form involves seeing specific letters or numbers (graphemes) in specific colors. For these individuals, known as grapheme-color synesthetes, an ordinary "5," in black ink on a white background, always appears red or a "k," greenish-blue.

According to research published in the March 24 issue of *Neuron*, not only do these grapheme-color synesthetes really see the colors they report, as measured in behavioral tests, but functional magnetic resonance imaging (fMRI) of their brains also shows activation in the color-selective regions of the cortex when they view black-and-white letters or numbers.

The results, say researchers from the University of California, San Diego and the Salk Institute for Biological Studies, lend support to the hypothesis that cross-activation of adjacent brain regions is the mechanism underlying synesthesia.

"We specifically designed our experiment to test the cross-activation hypothesis we initially advanced in 2001," said V.S. Ramachandran, a coauthor of the study and director of the Center for Brain and Cognition at UC San Diego. "The fMRI findings quite clearly demonstrate cross-activation - in this case between the number/letter region and color region of the fusiform gyrus in grapheme-color synesthetes."

When control subjects viewed numbers or letters, fMRI scans showed increased activity (increased blood-flow) only in the grapheme-selective regions of their brains, said Edward Hubbard, former UC San Diego graduate student and first author of the paper. Meanwhile, the hV4 area, a part of the brain network sensitive to and specialized for color perception, did not. In synesthetes, however, both regions "lit up."

In other words, in the synesthetic brain, the experience of a letter or number was activating both the standard, predictable area and "cross-activating" the color-selective area.

At the beginning of the project, the team first set out to determine whether synesthetes really see their reported colors. They started with behavioral measures. One test, for example, presented the subjects with a pattern of graphemes embedded in a matrix of other, distracting graphemes; 2's that formed a triangle, say, surrounded by 5's. If a synesthete saw 2's as a particular color, the triangle shape would pop out to them from an otherwise black-and-white field. Thanks to their synesthesia, went the thinking behind the task, synesthetes would be able to identify the embedded shapes more quickly than normal controls.

Most of the study's synesthetes (five of six) did indeed outperform control subjects in this task. But synesthetic colors were not as "strong" and not as effective an aid as real colors. Moreover, not all the synesthetes performed equally well.

Even more differences emerged among synesthetes when trying to identify letters or numbers in a crowded display in their peripheral vision.

These differences had been observed by scientists before, but it was difficult to gauge whether these were due to variance in the synesthetes or were primarily artifacts of differing research methods, Hubbard said.

The current study, the first to use both behavioral measures and neuroimaging in the same individuals, has allowed researchers to discern actual differences among synesthetes and to discover important correlations: The fMRI scans reveal that the stronger the activation of color-selective hV4 in a synesthete, the stronger the color perception and, consequently, the better the behavioral performance. "Synesthetes are likely to be far more variable that previous research has suspected," Hubbard said. "Further work in the field will need to address specific types of synesthetic experience."

Two such types, the researchers said, might be "higher" synesthetes, whose colors are driven by the concept of a letter or number, and "lower," whose colors are driven by the appearance of a letter or number. Ramachandran - who is beginning to image synesthetic brains with the Diffusion Tensor Imaging method (which captures the pathways of axons, the brain's connecting cells or "wires") - plans to work with higher synesthetes to see if they have not only cross-activation in the angular gyrus but also more wiring.

But why trouble with the strange, mixed-sense reality of synesthetes?

"By gaining an understanding of how the synesthetic brain functions we may gain an understanding of important aspects of human perception, cognition and development," said Hubbard. "For example, as the infant brain grows into the adult brain, regions that were connected to each other at birth are slowly separated or pruned. In synesthetes, however, it seems that this pruning process does not occur to the same degree. Understanding synesthesia may help us to better understand how a baby brain becomes sculpted into the adult form that we all have." Synesthesia may give us clues about how nurture and nature interact to lay down neural pathways, adds Ramachandran. And it provides a unique window into the mind.

"Synesthesia might tell us how the brain makes metaphors, which often take the form of cross-sensory associations - think "loud tie" or "sharp cheddar," Ramachandran said. "Processes similar to synesthesia may underlie our general capacity for metaphor and be critical to creativity.

"It is not an accident that the condition is eight times more common among artists than the general population," he said. "A quirky color/number synesthesia is not on the evolutionary agenda - but the ability for metaphor, a flair for connection, is. In fact, it's one of the hallmarks that makes us human."

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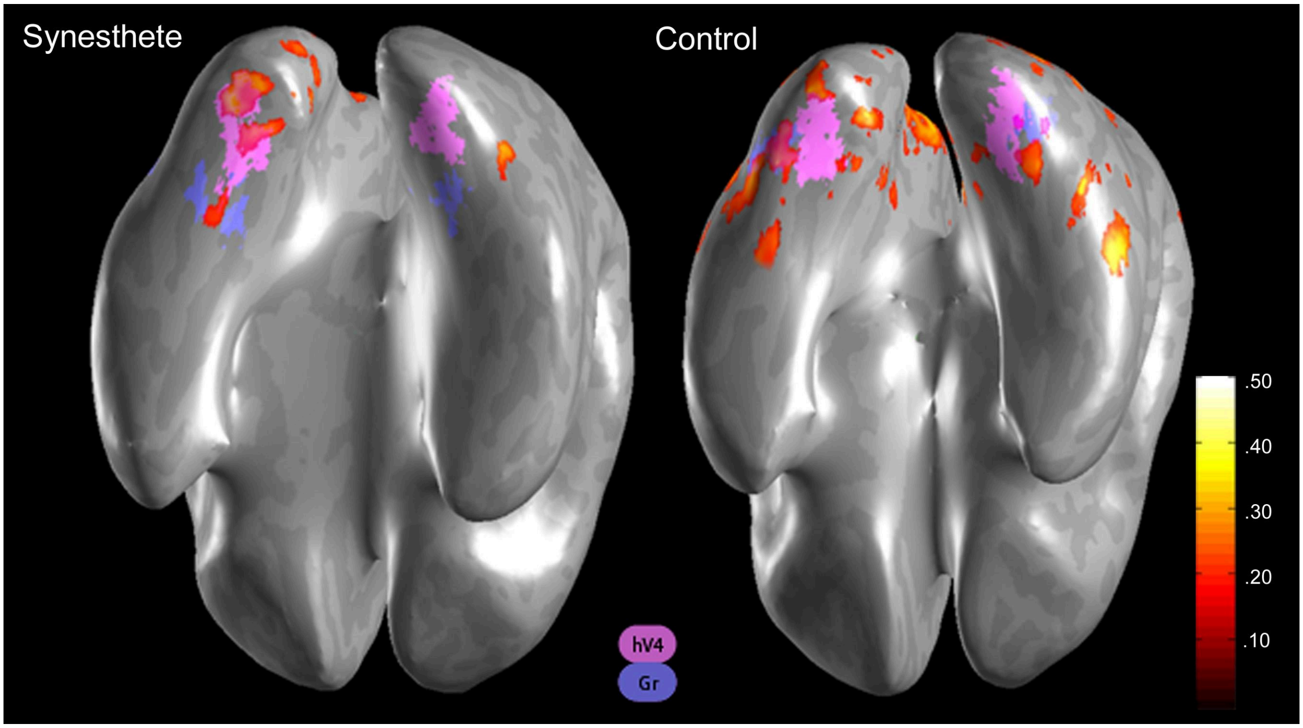
Geoffrey M. Boynton and A. Cyrus Arman, both of the Salk Institute for Biological Studies, collaborated on the project and are coauthors of the paper.

Media Contact: Inga Kiderra, (858) 822-0661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