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Color Synesthesia

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Synonyms

Color synaesthesia

Definition

Color synesthesia is a condition in which sensory or cognitive inducers elicit involuntary, atypical, concurrent color experiences.

Marks of Color Synesthesia

Synesthesia is a condition that involves unusual pairings across modalities. In color synesthesia, a sensory or cognitive stimulus such as a grapheme or a sound automatically and involuntarily induces specific color experiences. Various types of color synesthesia have been identified, including calendar-color synesthesia, sound-color synesthesia, taste-color synesthesia, and even fear-color synesthesia. However, the most prevalent form of the condition is grapheme-color synesthesia, where numbers or letters induce highly specific color experiences [1].

One of the marks of grapheme-color synesthesia is that it exhibits test-retest reliability, meaning that the synesthetic colors subjects identify relative to specific stimuli in the initial testing phase are nearly identical to those identified in retesting phases [1] (see Fig. 1).

Another mark of grapheme-color synesthesia is its uniqueness: synesthetic inducer-concurrent pairs are unique for each individual [1, 2]. For example, the letter A may induce a synesthetic experience of redness in one grapheme-color synesthete but a synesthetic experience of blueness in another. In fact, each grapheme has been found to trigger each of the 11 Berlin and Kay colors in different grapheme-color synesthetes (i.e., red, pink, orange, yellow, green, blue, purple, brown, black, white, gray). Another aspect of the uniqueness of the grapheme-color synesthesia is how the synesthetic colors are experienced [3]. Projector grapheme-color synesthetes see synesthetic colors as projected out onto the world. Pop-up effects are taken to be signifiers of projector synesthesia. Associator grapheme-color synesthetes, by contrast, experience colors in the mind's eye. Their synesthetic colors are triggered by automatic retrieval of mnemonic associations, which are

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Age/graph	0	1	2	3	4	5	6	7	8	9
3	/	B	Y	G	P	R	Bl	W	Br	R
4	/	B	Y	G	P	R	Bl	W	Br	R
5	Go	B	Y	G	P	R	DBr	W	Br	R
6	Go	B	Y	G	P	R	DBr	W	Br	R
7	B	B	Y	G	P	R	Br	W	Br	R
8	B	B	Y	G	P	R	Bl	W	Br	R

Color Synesthesia, Fig. 1 Example of test-retest reliability of synesthetic experience in one of the St. Louis Synesthesia Lab's associator grapheme-color synesthetes from ages 3 to 8 (Go = gold, B = blue, Y = yellow, G = green, P = purple, R = red, Bl = black, DBr = dark brown, Br = brown, W = white)

more akin to mental imagery than to remembering something learned in childhood [4]. Both projector and associator grapheme-color synesthesias involve the triggering of a highly specific and automatic inducer such as a colored letter or number.

Notwithstanding the individual differences among grapheme-color synesthetes, studies indicate that synesthetes show significant group preferences for certain grapheme-color associations [5]. For example, grapheme-color synesthetes tend to associate the letter *a* with red, the letters *i* and *o* with black or white, and the letter *n* with brown. These associations are not entirely random. While studies suggest that the experiences between grapheme-color synesthetes and non-synesthetes differ significantly, there are some common grapheme-color preferences among the two groups [6]. For example, both grapheme-color synesthetes and (forced- or free-choice) controls associate the letter *f* with green, the letter *b* with blue, and the letter *v* with purple.

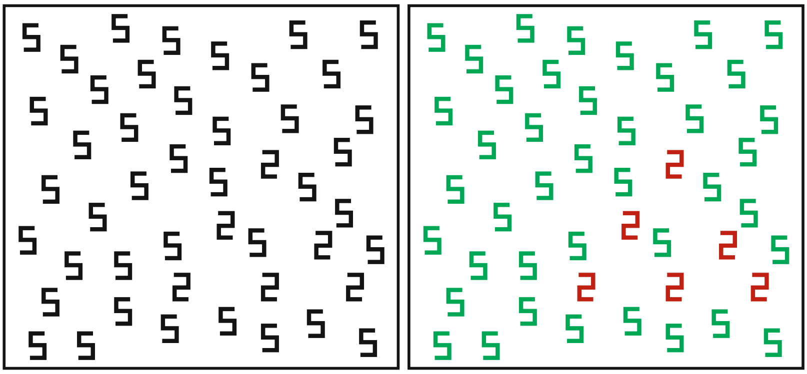
High-Level Versus Low-Level Synesthesias

An open question about grapheme-color synesthesia is whether it is triggered by low-level perceptual features (such as the curvature of the number 3) or high-level perceptual features of inducers (such as concepts inherent in a grapheme). Collectively, the evidence seems to indicate that both low- and high-level synesthesias occur in different individuals [4].

Some grapheme-color synesthetes seem to experience a pop-out effect in visual search experiments. For example, if a cluster of 2s is embedded in an array of randomly placed 5s, normal subjects take several seconds to find the shape formed by the 2s, whereas for some grapheme-color synesthetes, 5s pop-out instantly (see Fig. 2) [7].

Pop-out effects seem to indicate that some grapheme-color synesthesias are triggered by low-level perceptual features because they involve segregation. Specifically, grapheme-color synesthetes are able to experience the targets and the distractors as distinct stimuli: the 5s (which function as the target) are seen as forming a triangle and appear to be distinct from the 2s (which function as the distractors). Since only perceptual features processed early in visual processing can lead to segregation, pop-up effects seem to provide support for low-level grapheme-color synesthesias [7]. Pop-out effects are also taken to be evidence for projector grapheme-color synesthesias. Projector grapheme-color synesthetes see synesthetic colors as projected out onto the world. The induced colors (in Fig. 2) are experienced as belonging to the 2s and 5s seen on the template; they are not experienced as mere associations.

Visual search experiments that give rise to pop-out effects raise the question of whether synesthesia requires focused attention. If an inducer elicits synesthetic colors without it being attended, then a target (e.g., a 5 in Fig. 2) that has a distinct synesthetic color from a distractor (e.g., a 2 in Fig. 2) should capture attention and lead to highly efficient identification. But if an inducer does not



Color Synesthesia, Fig. 2 When normal subjects are presented with the figure on the *left*, it takes them several seconds to identify the hidden shape. Some grapheme-color synesthetes instantly see the *triangular* shape because they experience the 2s and the 5s as having different colors

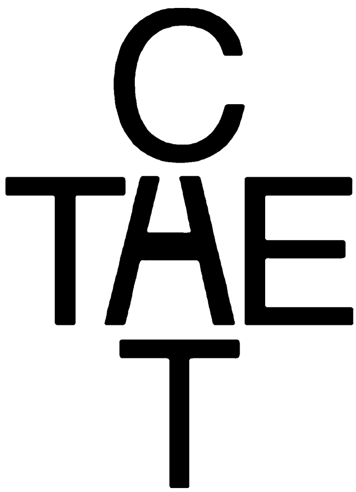
elicit synesthetic colors until it is attended, then the identification would be relatively inefficient.

Although some findings appear to suggest that pop-out effects occur preattentively, upon closer investigation, the current evidence indicates that an inducer does not elicit synesthetic colors until it is attended. One study [8] used a variation on the standard visual search experiment to test a subject's (J) search efficiency. J was shown an array of black graphemes on a colored background, some of which induced synesthetic colors. The colored background was either congruent or incongruent with the synesthetic color of the target. The researchers found that J was more efficient in her search when the background and the synesthetic color were incongruent than when they were congruent. This indicates that synesthetic colors attracted attention only when they were clearly distinct from the background. In another study, a subject, PM, was able to identify graphemes quickly but only when the target was within a few degrees of visual angle from fixation, indicating that PM's synesthesia is within the focus of attention [9].

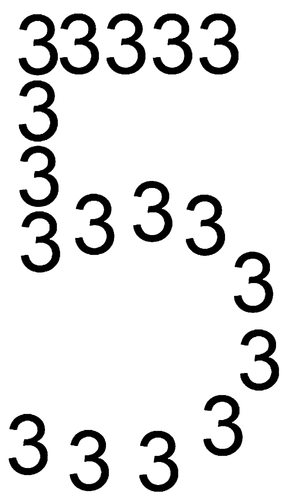
Other findings seem to nevertheless indicate the presence of low-level synesthesia. For example, one study found that the strength of the induced colors in one grapheme-color synesthete (JC) varied depending on whether the graphemes were presented in high or low contrast [10]. JC's synesthetic colors were reduced or absent at low contrasts but not at high contrasts. Since JC's synesthesia is elicited by low-level features (i.e., high contrast), this study indicates the presence of low-level synesthesia.

All of the aforementioned studies indicate the presence of low-level synesthesia. However, studies also seem to provide support for high-level synesthesias. In one experiment, a single grapheme induced different synesthetic colors depending on the context, e.g., the category or concept associated with the inducer. In one subject, the middle letter "H" induced a red synesthetic experience when she read the word shown in Fig. 3 as "CAT" but a brown synesthetic experience when she reads the word as "THE" [7].

In a similar experiment, color-grapheme synesthetes (JC and ER) were able to switch between their synesthetic colors when they were shown Navon-type figures such as an image of a large 5 constructed using smaller 3s (Fig. 4) [11]. For example, attending to the entire figure (i.e., the number 5) induced one synesthetic color, but attending to its parts (i.e., the smaller 3s comprising the 5) induced another. Similarly, when a display that could be viewed either as the letters I and V placed next to each or as the Roman numeral four, synesthetic colors were induced only in the former case [7]. The fact that the very same grapheme can induce different synesthetic colors depending on the context in which it occurs suggests that some grapheme-color synesthesias are triggered by high-level perceptual features. It is possible that such contextual effects associated



Color Synesthesia, Fig. 3 Synesthetes interpret the middle letter as an A when it occurs in "CAT" and as an H when it occurs in "THE." The color of their synesthetic experience will depend on whether the grapheme is considered part of the word "CAT" or "THE"



Color Synesthesia, Fig. 4 Some synesthetes are able to switch between their synesthetic colors when they were shown Navon-type figures such as an image of a large 5 constructed using smaller 3s. Two different synesthetic colors are induced depending on whether synesthetes attend to the entire figure, the number 5, or it's parts, the 3s that comprise the 5

with high-level synesthesia are the result of top-down modulation on early visual processing [7]. If so, these cases may turn out to be cases of low-level synesthesia.

Cognitive and Neural Mechanisms

The precise cognitive and neural mechanisms underlying color synesthesia are unknown. Some propose cognitive models of synesthesia based on the modularity thesis about processing. The modular theory holds that functionally individuated and introspectively opaque, encapsulated subunits of the mind process information in a way akin to a computer. One hypothesis is that synesthesia occurs when there is a breakdown in encapsulation between modules that process color and whatever other sensory or semantic features are involved [5, 12]. Others contend that synesthesia might result from the presence of an extra-module whose function is the mapping from a sensory or semantic input to a cross modal output [13].

A second type of account appeals more directly to the neural mechanisms underlying synesthesia. Structural connectivity mechanisms have been proposed for standard cases of grapheme-color synesthesia and sound-color synesthesia, suggesting unusual connectivity between color areas in the visual cortex and the adjacent visual word form area or the auditory cortex [7, 10]. Evidence for this hypothesis comes from brain-imaging studies showing enhanced anatomical connectivity near the implicated brain regions in grapheme-color synesthesia [14] and sound-color synesthesia [15].

Functional connectivity mechanisms have also been proposed for color synesthesia, according to which neural networks that give rise to synesthetic experiences exhibit excessive disinhibition or hyperexcitement of neurotypical connections through a change in neurotransmitters [16]. On one version of this hypothesis, color synesthesia is due to disinhibited feedback from an area of the brain that binds information from different sensory modalities [17]. Evidence for this hypothesis comes from an analogous case in which a patient PH reported seeing visual movement in response to tactile stimuli following acquired blindness [18]. As PH was blind, he could not have received the information via standard visual pathways. It is plausible that PM's synesthetic experience results from disinhibited feedback from brain regions that receive information from other senses.

The fact that synesthetic experiences can arise when subjects are under the influence of psychedelics provides further evidence for functional connectivity mechanisms [19, 20]. It has been shown in several studies that psychedelic hallucinogens that function primarily as serotonin agonists, such as psilocybin, LSD, and mescaline, often induce transient synesthesia, presumably through an alteration of functional brain connectivity [19, 21]. It is unknown, however, whether drug-induced synesthesia and developmental synesthesia have the same underlying mechanism.

On another version of the hypothesis that synesthesia is due to aberrant functional connectivity, color synesthesia arises as a result of aberrant reentrant processing [22]. This proposal is akin to the disinhibited feedback hypothesis but suggests specifically that high-level information reenters color areas in the visual cortex and that it is this form of reentrant information processing that leads to the experience of synesthetic colors. This model would explain why visual context and meaning typically influence which synesthetic colors a grapheme gives rise to [2].

Yet another hypothesis is that some forms of color synesthesia are learned in early childhood, for example, as a result of repeated exposure to refrigerator magnets [4]. Grapheme-color binding, for example, may in some cases be the result of enhanced activation of color areas in the visual cortex in response to automatically triggered semantic memory recall [23–25]. Whether color synesthesia can be acquired in adulthood through similar perceptual learning mechanisms remains to be seen.

It is plausible that different forms of color synesthesia proceed via different mechanisms. Cases of color synesthesia have been reported in which the visual cortex is not involved in generating synesthetic colors [26]. None of the aforementioned hypotheses, despite their plausibility in run-of-the mill cases, can explain more unusual cases of color synesthesia.

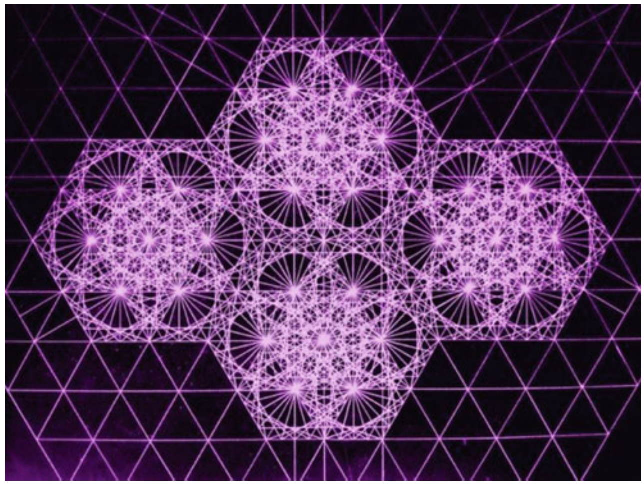
Cognitive Advantages of Color Synesthesia

Various cognitive advantages have been claimed for synesthesia. Some case studies suggest that grapheme-color synesthetes may have greater recall ability for digits and written names when compared to non-synesthetes [27].

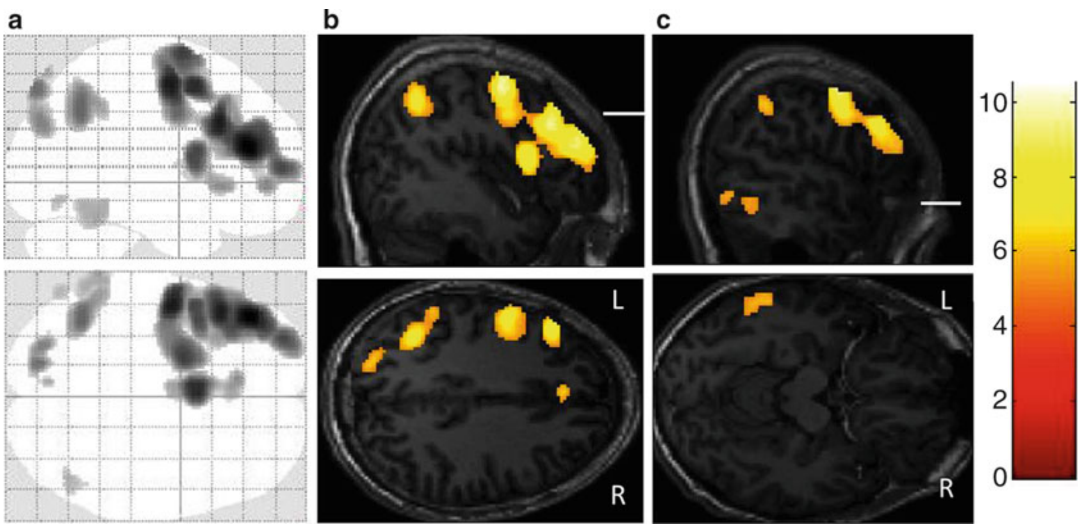
In rare cases, color synesthesia has been associated with extreme mathematical skills. Subject DT, for example, sees numbers as three-dimensional colored, textured forms [28]. His synesthesia gives him the ability to multiply high numbers very rapidly. He reports that the product of multiplying two numbers is the number that corresponds to the shape that fits between the shapes corresponding to the multiplied numbers. Subject DT's color synesthesia also gives rise to extreme mnemonic skills. DT currently holds the European record in reciting the decimal points of the number pi (π). An fMRI study comparing DT to controls while attempting to locate patterns in number sequences indicated that DT's synesthetic color experiences occur as a result of information processing in nonvisual brain regions, including temporal, parietal, and frontal areas [28]. This advantage may be facilitated by top-down modulation and has been used to support the view that photisms represent letterocity or numerocity [29].

Another subject, JP, was found to have exceptional abilities to draw complex geometrical images by hand and a form of acquired synesthesia for mathematical formulas and moving objects, which he perceives as colored, complex geometrical figures [26] (see Fig. 5).

JP's synesthesia began in the wake of a brutal assault that led to unspecified brain injury. A fMRI study contrasting activity resulting from exposure to image-inducing formulas and non-inducing formulas indicated that JP's colored synesthetic images arise as a result of activation in areas in the temporal, parietal, and frontal cortices in the left hemisphere. The image-inducing formulas as contrasted with the non-inducing



Color Synesthesia, Fig. 5 Image hand-drawn by subject JP



Color Synesthesia, Fig. 6 Sagittal slices. Activation induced by the image-inducing formula contrasted to non-inducing formulas. The SPM(T) maps were thresholded at family-wise-error-corrected p-value 0.01 and overlaid on JP's structural T1-weighted MRI which was standardized into MNI-space using SPM8 [26]

formulas induced no activation in the visual cortex or the right hemisphere [26] (see Figs. 5 and 6).

This case also suggests that at least some forms of color synesthesia can give rise to cognitive advantages in the area of mathematics. As the visual cortex does not appear to be directly involved in generating the synesthetic images, it also suggests that at least some forms of the condition are best characterized as forms of top-down modulation that proceeds via nonstandard mechanisms.

Enhanced creativity may be another advantage conferred by synesthesia. There is some evidence that synesthetes are on average more likely to work as artists [30, 31]. Both synesthesia and creativity involve linking unrelated ideas to reveal deep similarities, which may be due to the greater connectivity between processing areas [7].

Cross-References

- ▶ Afterimage
- ▶ Ancient Color Categories
- ▶ Appearance
- ▶ Chromatic Contrast Sensitivity
- ▶ Color and Visual Search, Color Singletons
- ▶ Color Constancy
- ▶ Color Contrast
- ▶ Color Phenomenology
- ▶ Color Processing, Cortical
- ▶ Color Psychology
- ▶ Color Synesthesia

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