FUNDAMENTAL NEUROSCIENCE
Paulik A. What color are your letters? - An insight into synesthesia. pp. 319 – 322

# WHAT COLOR ARE YOUR LETTERS? – AN INSIGHT INTO SYNESTHESIA

**Andrea Paulik**
*University of Zagreb, Faculty of Education and Rehabilitation Sciences*
0000-0002-9744-0613

## Abstract

Tuesday is a dark shade of blue. The sound of a train tastes like strawberries. For people with synesthesia, sensations in two modalities are experienced when only one is stimulated. Synesthesia can theoretically bind any two senses and there are 60 currently known synesthetic combinations, but research has largely focused on two of the most common variants in which auditory tones and colorless numbers produce vivid colors. It is commonly said that synesthesia is an involuntary, automatic, consistent and idiosyncratic condition, meaning that it does not happen consciously and that sensations evoked by stimuli do not change over time. It also means that no two people will have the exact same experience. For scientists, synesthesia presents an intriguing problem and more research is being conducted with the sole purpose of discovering where it originates from and how it works in the human brain. There are two main competing neurological hypotheses for synesthesia: crossmodal transfer (CMT) and neonatal synesthesia (NS). CMT is based on the idea that different sensory modalities and their functions are located in separated areas or modules of the brain, which are „cross-activated“ in synesthetes. NS is based on an assumption that ordinary neural pruning in human development fails to occur, leaving the individual with an originary, synesthetic brain.

**KEYWORDS**: cognitive neuroscience, crossmodal transfer, multisensory integration, perception, synesthesia

### INTRODUCTION

For years, the scientific community has been fascinated by the neurological phenomenon known as **synesthesia**. Synesthesia (from the Ancient Greek syn, "together", and *aisthēsis*, "sensation") is an experience in which stimulation in one sensory or cognitive stream leads to associated involuntary experiences in a second, unstimulated stream.[1,2] For example, numbers can be perceived in colors or taste may be experienced when hearing a specific word, as is shown in *Figure 1*. It does not apply to forced or acquired associations, such as the word Christmas having connotations with the colors red or green or the smell of cinnamon. The most commonly described forms are grapheme-color synesthesia and chromesthesia (sound to color). The first ever account of this subject was provided by Georg Ludwig Sachs in 1812.[3] He was the first to have written a scholastic description of synesthesia when the name itself did not even exist. In his doctoral thesis, he described the colors that he saw in his mind each time he thought of a letter or a number.

### INDUCERS AND CONCURRENTS

One of the things that a theory of synesthesia must explain is the pattern of inducers and concurrents. Inducers are the stimuli causing a conscious, involuntary, idiosyncratic, and stable (repeatable) experience of an atypical concurrent. The most common synesthetic inducers are linguistic in nature: letters, digits, and words – particularly words that form part of a series.[4] The most common synesthetic concurrents are visual in nature. This includes color and colored textures. It also includes spatial forms and shapes. However, there is a wide spectrum of possible inducers and concurrents, with new combinations still being discovered. *Figure 2* represents the most common forms of stimuli and corresponding elicited sensations.


**Figure 1.**
An example of synesthetic perception.
Based on references 1 and 2.
*Copyright © 2017 Andrea Paulik*

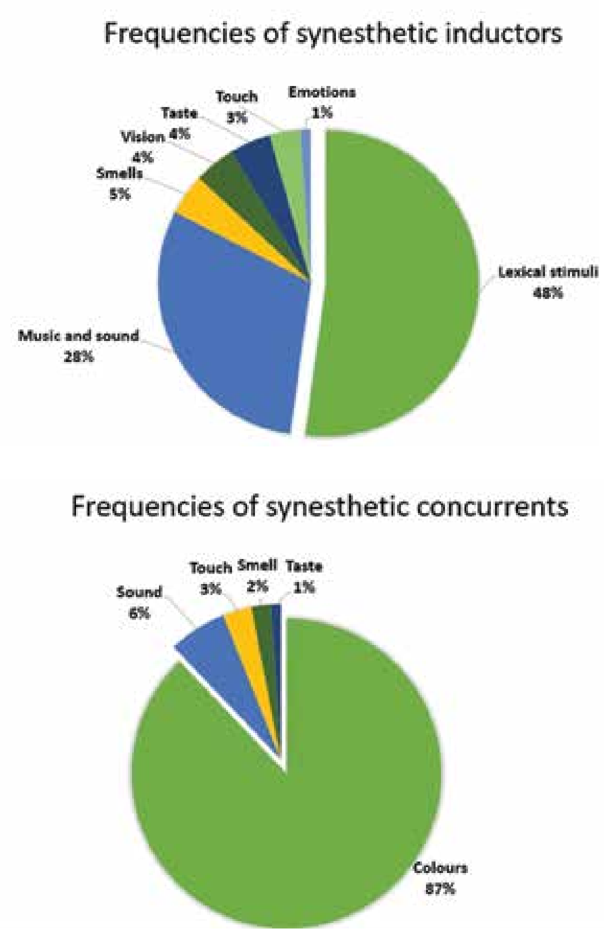


**Figure 2.**
The frequency of synesthetic inducers and concurrents.
Based on reference 4.
*Copyright © 2017 Andrea Paulik*

## EPIDEMIOLOGY

According to reported estimations, the prevalence of synesthesia is likely at about 5% or less.[5] The most widely cited study to date suggests that synesthesia occurs in at least 1 in 2000 people, although this is now generally regarded as an underestimation.[2] Subsequent large-scale studies have suggested the prevalence of synesthesia to be as high as 1 in 20 across all forms and 1 in 100 for grapheme-color synesthesia.[6] The inconsistency of the data might be the aftermath of differences in definitional criteria used by different researchers. Synesthesia is reported to emerge in early development and persist throughout life and likely has a genetic component.[2] While a proven genetic basis for synesthesia remains elusive, the phenomenon tends to run in families. However, symptoms vary greatly between all individuals with synesthesia, and no two people (not even parent-child pairs who experience the same general type of perceptions) will have the exact same experiences. Early research demonstrated that synesthesia is more common in women than men, leading to the belief that it follows an X-linked dominant mode of inheritance.[3] However, recent data shows that the genetic mechanisms that underlie this condition are more complex than the straightforward X-linked dominant account.[7] Previous findings may have been a result of underreporting by male subjects.

## NEURAL BACKGROUND

Synesthesia is often referred to as a neurological condition to emphasize the neural basis of the process. Various neural mechanisms play a role in these different types of synesthesia that may be linked to local cross-activations and re-entrant feedback mechanisms involving processed modalities in different brain areas that create various associations, e.g. word-color, tone-color, grapheme-color, and other forms of synesthesia.[8] For instance, a lexical-color synesthesia characterized by observation of an achromatic grapheme is related to specific neural signals from the retina that arrive to lower visual areas. Subsequently, these signals are processed by a shape-processing area (the posterior fusiform gyrus), and finally, they are processed in the area that is in charge of the interpretation of the meaning, in which the anterior fusiform gyrus plays a significant role.[9]

Among numerous speculations concerning the origins of synesthesia, there are two main competing neurological hypotheses for synesthesia: crossmodal transfer (CMT) and neonatal synesthesia (NS). One arises from the other, but they differ as to the developmental emergence and neurosystemic location of synesthesia.[7] CMT is based on the idea that different sensory modalities and their functions are located in separated areas or modules of the brain, which are “cross-activated” in synesthetes. In this model, cognitive abstraction makes sensory cross-modality possible. NS is based on the assumption that normal neural pruning in human development fails to occur, leaving the individual with an originary synesthetic brain. Here, it is suggested that complete nondifferentiation of sensory input supports movement between sensory pathways. These data are in agreement with the description of two basic forms of synesthetic experience, “lower” (referring to lower perceptual processes) and “higher” (referring to higher cognitive processes), in which the different forms of synesthesia represent different stages of brain processing.[6]

## FORMS OF SYNESTHESIA

Synesthesia comes in many different forms, with almost 60 known possible combinations.[10] Some of them are shown below in *Figure 3*. However, only three of the more common types of synesthesia are frequently studied and are better understood, which include grapheme to color and phoneme to color synesthesia. It is known that both of these types of synesthesia activate the fusiform gyrus, or the visual cortex, during synesthetic experiences.

| | | | | | |
|---|---|---|---|---|---|
| Grapheme | → | colour | Emotion | → | taste |
| Sound | → | colour | Sound | → | taste |
| Phoneme | → | colour | Sound | → | temperature |
| Smell | → | colour | Sound | → | smell |
| Touch | → | colour | Vision | → | smell |
| Emotion | → | pain | Vision | → | sound |
| Emotion | → | smell | Vision | → | taste |

**Figure 3.** Different forms of synesthesia.
Based on reference 10.
*Copyright © 2017 Andrea Paulik*

FUNDAMENTAL NEUROSCIENCE
Paulik A. What color are your letters? - An insight into synesthesia. pp. 319 – 322

## GRAPHEME-COLOR SYNESTHESIA

Like all forms of synesthesia, grapheme-color synesthesia is involuntary, consistent, and memorable. Hubbard & Ramachandran (2005) and Hubbard (2007) proposed an influential two-stage model for it.[1,6] According to their model, synesthetic experience arises from abnormal crossactivation between the grapheme area and the color area in the fusiform gyrus (FG) due to synesthesia-specific local connections. The fusiform gyrus has been linked with various neural pathways related to recognition. The synesthetic color perceptions driven by the FG are then thought to be bound together by top-down mechanisms controlled by the parietal cortex, this in turn resulting in a kind of "hyperbinding". This two-stage model was developed on the basis of several studies that reported neuronal correlates for grapheme–color synesthesia. One of those studies has noted that the human V4 (hV4) region in the FG is consistently more active in synesthetes than in non-synesthetes, when presented with colorless grapheme stimuli. That is an area responsible for the representation of colors. It was evident in fMRI studies that activation of the hV4 region was greater in grapheme-color synesthetes than in non-synesthete controls *(Figure 4)*.[11]

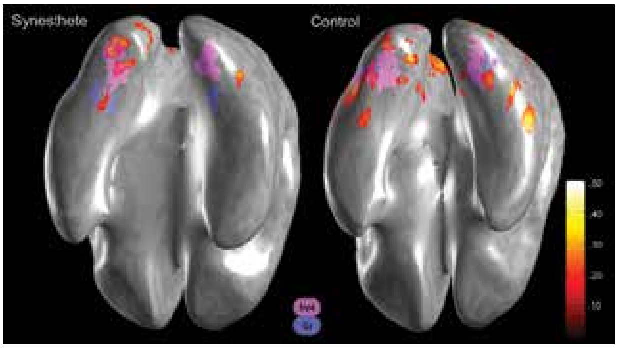


**Figure 4.** fMRI of ventral surface activation in synesthetes and non-synesthete controls during a grapheme stimulus. The hV4 region is shown in purple and the grapheme area is shown in blue. The grapheme area was equally active for both synesthetes and the control group, but the hV4 region was active only in synesthetes. *Source: Hubbard EM, Arman AC, Ramachandran VS, Boynton GM. Individual Differences among Grapheme-Color Synesthetes: Brain-Behavior Correlations. Neuron. 2005;45(6):975-985. doi:10.1016/j.neuron.2005.02.008. Available under an Elsevier user license (https://www.elsevier.com/about/policies/open-access-licenses/elsevier-user-license).*


A study conducted by Weiss and Fink[12] showed that grapheme-color synesthetes have increased grey matter volumes of parietal and fusiform cortex. New studies should address the question of whether the observed structural differences in the FG and intraparietal areas precede or result from synesthetic experiences.

## CHROMESTHESIA – COLORED HEARING

While the structural and functional differences in the synesthete brain provide clear evidence for a neural basis of synesthetic perception, most of these findings come from grapheme-color synesthesia, in which inducer and concurrent processing regions may be anatomically adjacent.[13] Thus, these findings may not generalize to other forms of synesthesia, in which inducer and concurrent are processed in non-adjacent regions in the cortex, such as chromesthesia. With sounds inducing color concurrents, chromesthesia is more accurately termed sound-color synesthesia. Individuals with sound-color synesthesia are consciously aware of their synesthetic color associations in daily life. Chromesthesia evokes strong emotional connections to music because the listener associates different pitches and tones to certain colors, which in turn, produces specific feelings.[14] Most synesthetes have reported that they don't encounter color visually when listening to music; rather, they feel and experience the color that comes with hearing a certain tone. Some researchers suggest that chromesthesia can be acquired by damage to the retino-cortical pathway.[15]

The previous studies led some researchers to a new hypothesis: if color processing in visual association regions and music or auditory processing in auditory association regions (superior temporal gyrus, superior temporal sulcus, middle temporal gyrus) are more closely connected, then the white matter pathways that pass through these regions might be different in colored-music synaesthetes.[15] Results showed that people with colored-music synesthesia possess enhanced structural connectivity between the frontal lobe and visual and auditory association areas. Compared to controls, colored-music synesthetes possess different hemispheric patterns of white matter integrity in the inferior fronto-occipital fasciculus (involved in multimodal integration, visual information processing and processing of speech and language input).

## CALL FOR RESEARCH

Although fairly prevalent in the general population, synesthesia is still an intriguing condition. While scientists have known about it for nearly two centuries, only recently have researchers – across the fields of neuroscience and psychology – been able to focus their studies in the direction of finding out how the brain of a synesthete works.

There were numerous studies regarding synesthesia conducted in the previous decade by scientists from the Max-Planck Institute for Brain Research in Frankfurt. They provided us with a different perspective on the subject, proposing that synesthesia is not a sensory-sensory phenomenon but instead a semantic-sensory one in which the meaning of the stimulus induces perception-like experiences.[16] That is why Dr. Danko Nikolić, a Croatian scientist working in the above mentioned institute, proposed another term for synesthesia: *ideasthesia*, which is Greek for "sensing concepts". The theory of ideasthesia is based on evidence for introducing a semantic component into the definition of this condition and furthermore proposes a mechanism through which the semantic system contributes to the phenomenon.[16]

Understanding the development of a synesthetic brain helps researchers to understand the development of sensory and perception systems. Future research should address synesthesia as a foundation from which they could begin to understand the diversification of human experiences and functions of the human brain.

# REFERENCES:


1. Hubbard EM. Neurophysiology of Synaesthesia. *Curr Psychiatry Rep.* 2007;9(3):193-199. doi:10.1007/s11920-007-0018-6.
2. Baron-Cohen S, Burt L, Smith-Laittan F, Harrison J, Bolton P. Synaesthesia: Prevalence and Familiality. *Perception.* 1996;25(9):1073-1079. doi:10.1068/p251073.
3. Jewanski J, Day SA, Ward J. A Colorful Albino: The First Documented Case of Synaesthesia, by Georg Tobias Ludwig Sachs in 1812. *J Hist Neurosci*. 2009;18(3):293-303. doi:10.1080/09647040802431946.
4. Simner J, Mulvenna C, Sagiv N, et al. Synaesthesia: The Prevalence of Atypical Cross-Modal Experiences. *Perception.* 2006;35(8):1024-1033. doi:10.1068/p5469.
5. Ward J. Synaesthesia. *Annu Rev Psychol.* 2013;64:49-75. doi:10.1146/annurev-psych-113011-143840.
6. Hubbard E, Ramachandran VS. Neurocognitive Mechanisms of Synaesthesia. *Neuron.* 2005;48(3):509-520. doi:10.1016/j.neuron.2005.10.012.
7. Munster A. *An Aesthesia of Networks: Conjunctive Experience in Art and Technology*. London, UK: MIT Press; 2013.
8. Neckar M, Bob P. Neuroscience of synesthesia and cross-modal associations. *Rev. Neurosci.* 2014;25(6):833-840. doi:10.1515/revneuro-2014-0033
9. Hochel M, Milán EG. Synaesthesia: The existing state of affairs. *Cogn Neuropsychol*. 2008;25(1):93-117. doi:10.1080/02643290701822815.
10. Day SA. Synaesthesia: A first-person perspective. In: Simner J, Hubbard EM, eds. *The Oxford Handbook of Synaesthesia*. New York, NY: Oxford: University Press; 2013: 903-923.
11. Hubbard EM, Arman AC, Ramachandran VS, Boynton GM. Individual Differences among Grapheme-Colour Synesthetes: Brain-Behavior Correlations. *Neuron.* 2005;45(6):975-85. doi:10.1016/j.neuron.2005.02.008.
12. Weiss PH, Fink GR. Grapheme-colour synaesthetes show increased grey matter volumes of parietal and fusiform cortex. *Brain*. 2009;132(1):65-70. doi:10.1093/brain/awn304.
13. Zamm A, Schlaug G, Eagleman DM, Loui P. Pathways to seeing music: Enhanced structural connectivity in colored-music synesthesia. *Neuroimage.* 2013;74:359-366. doi:10.1016/j.neuroimage.2013.02.024.
14. Makhlin J. Chromesthesia as Phenomenon: Emotional colors. *Writing Programs.* 2014; Paper 12. *https://digitalcommons.lmu.edu/arc_wp/12/*. Accessed September 26, 2017.
15. Ward J, Huckstep B, Tsakanikos E. Sound-Colour Synaesthesia: to What Extend Does it Use Cross-Modal Mechanisms Common to us All? *Cortex.* 2006;42(2):264-280. doi:10.1016/S0010-9452(08)70352-6.
16. Nikolić D. Synesthesia / Ideasthesia. http://www.danko-nikolic.com/synesthesia-ideasthesia/. Accessed October 18, 2017.


# KOJE SU BOJE TVOJA SLOVA? – UVID U SINESTEZIJU

## Sažetak

Utorak je tamno plav. Zvuk prolazećeg vlaka ima okus po jagodama. Za osobe sa sinestezijom, stimulacija jednog modaliteta može dovesti do doživljaja u dva modaliteta. Teoretski, sinestezija može povezati bilo koja dva senzorna modaliteta te danas imamo oko 60 poznatih kombinacija, no istraživanja su se najviše usredotočila na dva najčešća oblika u kojima zvuk ili grafem (slovo ili broj) dovode do percepcije boje. Često se kaže kako je sinestezija nevoljno, automatsko, trajno i idiosinkratsko stanje, što znači da se ne događa na svjesnoj razini i da se doživljaji pobuđeni podražajem ne mijenjaju kroz vrijeme. To također znači da niti jedna dva sinesteta neće proživjeti isto iskustvo. Sinestezija za znanstvenike predstavlja intrigirajući problem te se sve više istraživanja provodi u svrhu određivanja podrijetla ove pojave i kako funkcionira u mozgu. Postoje dvije glavne hipoteze: prva je teorija o kros-modalnom transferu (engl. CMT), a druga o neonatalnoj sinesteziji (engl. NS). CMT je teorija bazirana na činjenici da su različiti senzorni modaliteti i njihove funkcije smješteni u različitim dijelovima mozga te da se kod sinesteta ukršteno aktiviraju. NS je temeljena na pretpostavci da se normalni neurorazvojni proces koji se odvija u neonatalnom razdoblju, tzv. sinaptičko obrezivanje (engl. *pruning*), ne odvije u slučaju sinestezije te osoba doživljava navedene aspekte stanja.

**KLJUČNE RIJEČI:** kognitivna neuroznanost, križnomodalitetni transfer, multisenzorna integracija, percepcija, sinestezija

*Received June 13, 2017.*
*Accepted November 1, 2017.*