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Zelazny, Aurore; Sørensen, Thomas Alrik

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SYNESTHESIA—ARE ALL MONDAYS BLUE?

***Aurore Zelazny*[1,2*†] *and Thomas Alrik Sørensen*[1,2†]**

[1] Centre for Cognitive Neuroscience, Department of Communication and Psychology, Aalborg University, Aalborg, Denmark
[2] Sino-Danish College (SDC), University of Chinese Academy of Sciences, Beijing, China

YOUNG REVIEWERS:

ASHMITA
AGE: 15

LICEO SCIENTIFICO M. G. AGNESI
AGES: 14–15

Does Monday have a specific color? What does the ABC song taste like? These may sound like strange questions, but for a small number of people, such questions may be very reasonable. This is due to a phenomenon called synesthesia. It originates from Greek, meaning "joined" (syn) and "sensations" (esthesia). We experience the environment through a range of senses. You may hear music with your ears or enjoy the color of a clear sky with your eyes. However, when someone has synesthesia, certain experiences seem to have an additional sensory dimension. So, on top of hearing music, a person with synesthesia may also see the song in front of them. The phenomenon is still not fully understood. However, there are several suggestions about its mechanisms. Synesthesia provides an insight into individual differences in how we experience the world we live in.

WHAT IS SYNESTHESIA?

When navigating the environment, our senses collect information. Sensory information is then processed by the brain to guide our actions and behaviors. We tend to assume that when we see an object, say an apple, everyone else sees and experiences the apple the same way. Philosophers have debated whether we can ever be sure about other people's experiences. Examples continually emerge indicating that people have different ways of experiencing the world. **Synesthesia** is one such example, demonstrating that sensory experiences can vary between observers. Synesthesia is derived from the Greek words "syn," meaning "joined," and "esthesia," meaning "sensations." Synesthesia is estimated to occur in about 4% of the population. Synesthesia can vary between people because there are many different types of synesthesia. One estimate is that there are at least 70 different variations[1]. Some people experience colors when they see letters [1]. For others, weekdays have a specific color, for example Monday is red and Tuesday is yellow. There are also people who taste words.

SYNESTHESIA

A brain phenomenon in which a stimulus triggers a typical sensation, such as seeing the letter "A," followed by an unrelated sensation, like seeing the color yellow.

[1] http://www.daysyn.com/Types-of-Syn.html

In the example in which Monday is red, we call Monday the **inducer**, because it *causes* the synesthesia experience. We call red the **concurrent**, because it is the sensory experience that *follows* from thinking about Monday. A person who experiences synesthesia is commonly called a **synesthete**. A synesthete may have several types of synesthesia in varying degrees. In other words, there is a wide range of different experiences a synesthete may have.

INDUCER

The piece of information that causes a synesthesia experience, such as a letter, a number or a song.

CONCURRENT

The unrelated sensation that comes as a reaction to certain stimuli, as such the color sensation that follows seeing a letter.

SYNESTHETE

A person who experiences synesthesia.

If there is that much variation, how are we sure that all the examples are synesthesia? Not all synesthetes would associate the number 4 with the same color, for example. Nevertheless, all types of synesthesia share some common features. One is that the associations seem stable over time. Imagine a person for whom the letter A is a particular hue of red. That person will report the same red hue when asked about it even weeks apart.

Figure 1 shows drawings from Anneline, who is a synesthete. She made a drawing of her synesthesia for numbers and shapes back in 2013 (Figure 1A). Seven years later, we asked her to redraw how she experiences numbers and shapes (Figure 1B). Anneline has several forms of synesthesia, and among these, she experiences colors for numbers and shapes. Numbers are also associated with various sizes. Interestingly, this size difference does not correspond to the numeric quantity. She would describe the number six as very annoying due to its small size, making it very difficult to see. However, she likes the number five because it is large, orange, and easy to see.

In addition to synesthetes' direct descriptions of their synesthesia, it is possible to demonstrate in the lab that these associations influence perception. Synesthetes process letters faster when the letters are shown in their synesthetic color. Synesthetes also have to use fewer

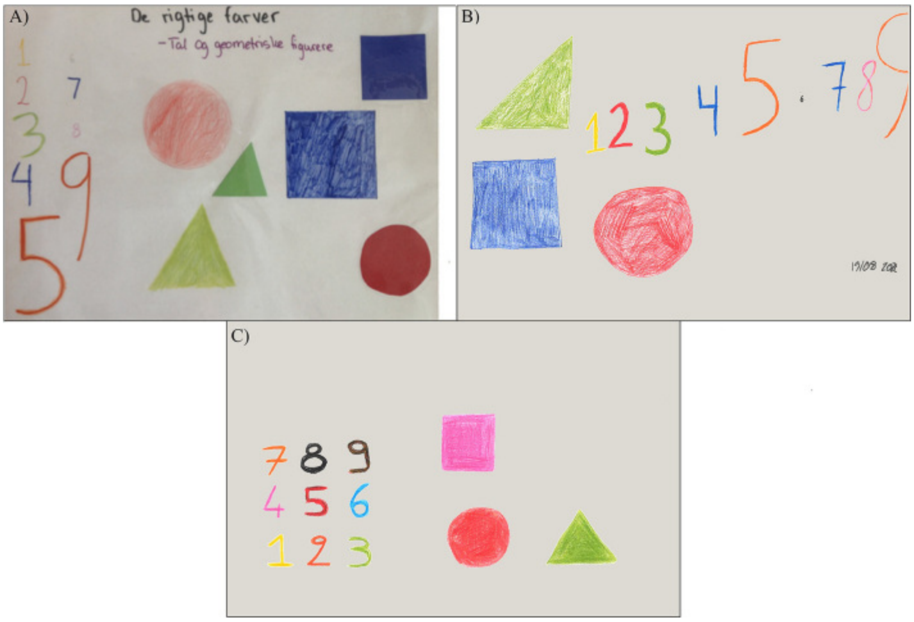

Figure 1

Figure 1

Synesthesia for numbers and shapes. **(A)** A drawing from Anneline in 2013, with the title "the correct colors—numbers and geometrical shapes." Her drawing shows the colors and sizes each number has for her. **(B)** Another drawing by Anneline in 2020. Seven years later, her colors and sizes have not changed. **(C)** Drawing by Aurore in 2020. She has different color profiles for numbers and shapes. A few colors are similar to Anneline's (1, 2, 3, for example), while others (4, 5, square) are very different.

memory resources than they do if the letters are shown in a different color [1].

Four different explanations for synesthesia have been suggested. The cross-activation theory, the disinhibited **feedback** theory, the re-entrant hypothesis, and the developmental learning hypothesis.

FEEDBACK

A process of information traveling from the associative area back to the sensory area.

TOO MANY CONNECTIONS IN THE BRAIN

To understand the first explanation, we can think about the brain as a house. We first need to build the house. This happens before we are born and for the first couple of years of our lives. We say that the brain is maturating. But this is a strange house in the beginning. The builder is not sure how we will want to use various rooms. Therefore, he connects every electrical switch to several different outlets. What does it mean for the brain? It means that there are way too many connections between brain cells (called neurons) and between various areas of the brain. When people move into the house, they decide where to plug in the lamps, the TV, the toaster, etc. They call in an electrician and ask him to remove all the cables that connect switches to the wrong outlets. Now, when the people want to turn on the kettle, they know which switch to use—that switch now turns on the kettle only.

A similar process happens in the brain when children are about 2 years old. A child's experiences of the world will decide which brain connections are useful. The useless ones will disappear while the useful ones will become stronger. We call this process **pruning**. In

PRUNING

A brain process in which connections between neurons that are not used are removed. At the same time, useful connections are strengthened.

the case of synesthesia, the cross-activation theory [2] suggests that the electrician forgot one of the useless connections. Now, when people turn on their living room light, it also turns on the TV! In other words, some brain connections that were supposed to disappear have remained (Figure 2A). When the synesthete hears music, the information goes to their auditory (hearing) system, as expected. However, it also activates parts of the visual system. So, that person may see shapes or colors every time they listen to a song.

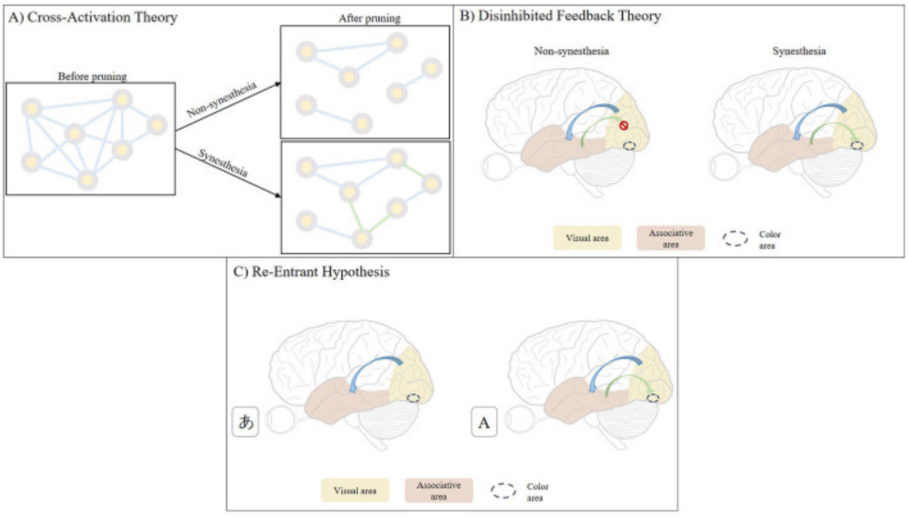

Figure 2

Figure 2

(A) The cross-activation theory states that, in synesthesia, some useless brain connections are not pruned as they are in non-synesthetes, keeping unrelated brain areas connected (green lines). **(B)** The disinhibited feedback theory states that, in synesthetes, information travels back (green arrow) to parts of the brain. In non-synesthetes, this feedback is inhibited. **(C)** The re-entrant hypothesis states that, when seeing a letter a synesthete recognizes, a feedback process (green arrow) will occur, but when seeing a letter she does not recognize, no feedback will be initiated.

OOPS, WRONG WAY!

According to the second explanation, synesthesia is not due to differences in the structure of the brain. Instead, this explanation hypothesizes that synesthesia comes from differences in the way people process sensory information. Let us take the example of someone reading the letter A. Information first enters through the person's eyes, then it arrives at the visual area, at the back of the brain. This is called a **sensory area**. Here, the information is analyzed in several steps. We can imagine it as an assembly line, in which each worker evaluates a specific aspect of the information, spotting whether it contains a straight line, if the image is moving, or if it is colored, for example. Once the image has been analyzed, the information moves on to be processed in the **associative areas** of the brain. There, the information from various sources is combined. Naming the letter, or listing words that start with A, are examples of associative tasks. Once the information has been processed by the associative areas, it travels back to the sensory area. This process is called feedback. However, since the information has already been treated there, it does not get passed on further—we say that it is *inhibited*. The disinhibited feedback theory [3] suggests that, in synesthetes, the inhibition process may not occur correctly (Figure 2B). Instead, the information gets analyzed in the sensory area one more time. Take the case of Anneline. Every time

SENSORY AREA

Brain areas that process information from our senses—sight, hearing, touch, etc.

ASSOCIATIVE AREAS

Brain areas in which information from the various senses is combined. More complex processes occur, such as understanding and reacting to what we read.

an A is sent back to the visual sensory area, is it also labeled with the additional sensation of yellow.

The re-entrant hypothesis [4] is a variation of this idea (Figure 2C). In the disinhibited feedback theory, visual information is spontaneously sent back from the associative area to the sensory area. However, according to the re-entrant hypothesis, this feedback process is not spontaneous—it can happen *only* if the meaning of the letter is known. Take Anneline, who can read English and Danish. Now imagine we show her the Japanese grapheme?, which is equivalent to A. She will not get any colored response to it, as her brain does not know what it means. Aurore however can read Japanese. When she sees?, she experiences pink (Figure 1C).

A LEARNING TRICK OF THE MIND

The three hypotheses presented so far try to explain how the brain of a person with synesthesia functions. They do not try to explain why only *some* people have synesthesia. You may have noticed that the inducers, like letters or months, are concepts that we do not know from birth. We learn about these concepts as we grow up, and they are not the same in every culture. For example, not all languages are written with the same symbols. This led researchers to wonder whether synesthesia is involved in the learning process. Learning every letter and being able to use them all is a difficult task for some people. So, it is possible that their brains came up with a trick. Their brains slowly started to associate the concept of the letter A to a specific color, to help them tell the difference between letters. A similar process may occur for all types of synesthesia inducers. Researchers call this explanation the developmental learning hypothesis [5].

SUMMARY

Synesthesia gives people a particular experience of the world. The origin of synesthesia is still a mystery to researchers. However, great progress has been made, and we now know more about the different profiles of synesthetes. We also have some hypotheses regarding the brain mechanisms involved. Understanding synesthesia can help us understand the individual differences in how our brain processes information. It could help us discovering new ways to overcome learning difficulties.

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YOUNG REVIEWERS

ASHMITA, AGE: 15

A highschool student greatly driven by her fiery passion and love for learning. Her interests include:

~Psychology 

~Neuroscience 

~Education 📚

~Health & Wellness 🧘

~Kinesiology 🦿

~Leadership 💂

~Social Justice ⚖️

~Dance 💃

Apart from school, she spends much of her time working for and running organizations. She is a mental health and social justice advocate and devotes many hours raising awareness on issues important to her, especially by participating in media-based organizations. In her free time, she enjoys reading books 📖, listening to music 🎧, binging TV shows 📺, hanging out with friends 👭, dancing 💃, and exploring new things 🥺. She is also a BTS ARMY 💜.

LICEO SCIENTIFICO M. G. AGNESI, AGES: 14–15

Hi, we are the class 1AS from the Liceo Scientifico M.G. Agnesi, in Italy. We think this was a really good project and could be quite useful to some of us in the future. We found it very interesting because we learned things we did not know before: it gave us a chance to expand our curiosity and our knowledge.

AUTHORS

AURORE ZELAZNY

I have always been fascinated by languages and the brain. I started off studying linguistics, then I became interested in how language works in the brain. As a synesthete myself, I wondered whether synesthesia is related to early language learning. I am interested in how synesthesia is involved in acquiring expert knowledge of new concepts. I work at the Center for Cognitive Neuroscience at Aalborg University in Denmark. *aurore@hum.aau.dk

THOMAS ALRIK SØRENSEN

I have a keen interest in memory and perception and how expertise influences perceptual processes. During my Ph.D. at the University of Copenhagen I started to investigate how short-term memory was influenced by various factors, which has since led to a more general interest in what shapes the way we experience our environments. Synesthesia is a particularly interesting phenomenon, as synesthetes clearly demonstrate a difference in perceptual content compared to non-synesthetes, which may help us to better understand what drives individual differences in perception. I am heading the Center for Cognitive Neuroscience at Aalborg University.

[†]These authors have contributed equally to this work and share first authorship