https://doi.org/10.48047/AFJBS.6.15.2024.10276-10291

AFJBS

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

SYNESTHESIA: AN OVERVIEW OF SENSORY CONFLUENCE

Parameshwari M[1], Nithya Varadarajan[2], Dinakaran kannappan[3], Vinod Kumar kaluram[3], Bellarmin Michael[3], Sheela Manickam[3], Saranya Punniyakotti[4], Afraahsulthana R[3]*

[1]Research Scholar, Saveetha College of Pharmacy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai, Tamil Nadu, India

*[2]Associate Professor and Head, Department of Pharmacy Practice, Saveetha College of Pharmacy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai, Tamil Nadu, India

[3]Saveetha College of Pharmacy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai, Tamil Nadu, India

[5]Professor, Department of Pharmacy Practice, Saveetha College of Pharmacy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai, Tamil Nadu, India

***Corresponding author**: Dr Nithya Varadarajan

Associate Professor and Head,

Department of Pharmacy Practice,

Saveetha College of Pharmacy,

Saveetha Institute of Medical and Technical Sciences (SIMATS),

Thandalam, Chennai,

Tamil Nadu, India – 602105.

Mobile No: +91-9962579060

Mail id - drnithyapunniyakodi@gmail.com

Volume 6, Issue 15, Sep 2024

Received: 15 July 2024

Accepted: 25 Aug 2024

Published: 25 Sep 2024

doi: 10.48047/AFJBS.6.15.2024.10276-10291

ABSTRACT

This review article provides a comprehensive examination of synesthesia, a phenomenon characterized by the involuntary blending of sensory experiences. It explores the various forms of synesthesia, including grapheme-color and sound-color synesthesia, and highlights the consistency and vividness of synesthetic perceptions. The article delves into the theoretical explanations of synesthesia, discussing hypotheses such as cross-activation, disinhibited feedback, and hyperconnectivity theories. It also explores the neural mechanisms underlying synesthesia, focusing on brain regions involved in sensory processing. The review examines the genetic underpinnings of synesthesia, discussing the heritable component and the identification of candidate genes. It also considers the role of environmental factors in shaping synesthetic experiences. The broader implications of synesthesia are discussed including potential benefits such as enhanced memory and creativity, as well as challenges in daily life.

Overall, this review article provides a comprehensive understanding of synesthesia, shedding light on its various forms, theoretical explanations, genetic basis, and broader implications. It could be a valuable tool for researchers and scientists who wish to investigate the fascinating interaction between perception, cognition, and the human brain.

KEYWORDS

Synesthesia, Cross-activation, Genetic predisposition, Sensory Blending, Grapheme colour synesthesia, Misophonia

1. INTRODUCTION

Synesthesia is a neurological phenomenon characterized by the blending or crossing over of different sensory or cognitive pathways in the brain. This leads to the activation of a sensory or cognitive pathway which causes involuntary and consistent experiences in another pathway. As an instance, someone with synesthesia may always visualize colors while listening to music, thinking about letters or link distinct tastes to particular words (Figure 1). It's a distinct and steady blending of sensory experiences that differs among individuals (1–3).

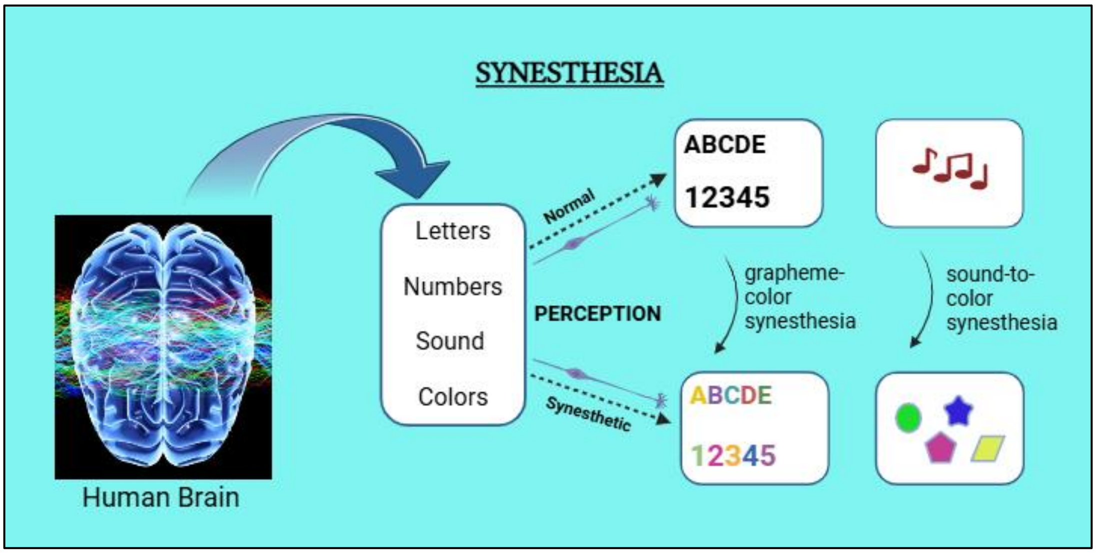

Figure 1. Illustration depicting the differences in sensory perception by normal and synesthetic brain. Synesthesia is a rare perception disorder that results due to the activation of more than one sensory area in the brain. Grapheme-color synesthesia patients perceive letters and numbers in a colorful way, whereas sound is perceived in a colorful form in sound-color synesthesia. Created using BioRender.com.

Synesthesia, a captivating and mysterious phenomenon, has fascinated researchers across disciplines. This comprehensive review explores the diverse forms, underlying mechanisms, and neurocognitive implications of synesthesia. From grapheme-colour synesthesia to sound-colour synesthesia, the range of synesthetic experiences is vast (4). While the exact causes are still being investigated, genetic predisposition and neural connectivity alterations are potential contributors. One neurobiological theory proposes that synesthetic experiences occur due to neural signals connecting the inducer pathway and the concurrent pathway. This theory provides a framework for understanding synesthesia's manifestation and analysis. Synesthesia also offers insights into the processing of speech, faces, and mental imagery (4,5). By studying individuals with synesthesia, researchers gain valuable insights into the neural mechanisms involved in these cognitive processes. This review is a helpful tool for gaining insight into the mysterious realm of synesthesia and how it affects perception and cognition.

2. CHARACTERISTICS OF SYNESTHESIA

2.1 Involuntary and Automatic Nature

Synesthetic encounters are spontaneous and uncontrollable, arising without intentional direction. This inherent quality distinguishes them from deliberate sensory associations and underscores the automatic fusion of sensory inputs.

2.2 Sensory Blending

Synesthesia entails the fusion of sensory perceptions, where one type of stimulation triggers experiences in another sensory modality. This blending reveals the brain's capacity to intertwine distinct sensory pathways.

2.3 Consistency Over Time

Synesthetic pairings remain remarkably stable across an individual's lifespan. The enduring nature of these associations implies a steadfast neural architecture and potential ties to memory systems.

2.4 Cross-Modal Associations

Synesthesia hinges on cross-modal connections, creating links between sensory domains that conventionally operate independently. These associations provide insights into the brain's adaptable sensory processing.

2.5 Subjective Variability

While general patterns exist, synesthetic manifestations vary significantly among individuals. This individualistic trait suggests a complex interplay between genetic factors, neural circuitry, and individual experiences.

2.6 Enhanced Memory and Perception:

Synesthetes often exhibit enhanced memory and perception in synesthetic realms. This phenomenon underscores potential cognitive advantages tied to the interconnectedness of sensory experiences (4,6).

3. PATTERNS OF SYNESTHESIA

The different forms of synesthesia have been explained below and illustrated in Figure 2.

a. Grapheme – color synesthesia

In one of the most common forms of synesthesia, specific colors are associated with individual letters and numbers, known as "graphemes", as if they were being colored or tinted. While the specific colours associated with each grapheme can vary between individuals, research involving a large number of synesthetes has identified some shared tendencies (for example, the letter "A" often being linked with the colour red). Some researchers claim that the term "synesthesia" may not be suitable for describing conditions like grapheme-color synesthesia, in which the stimulus is a concept (such as a letter or number) rather than a sensory experience (such as sound or color). As an alternative, they suggest the term "ideasthesia" as a potentially more precise description (1,2).

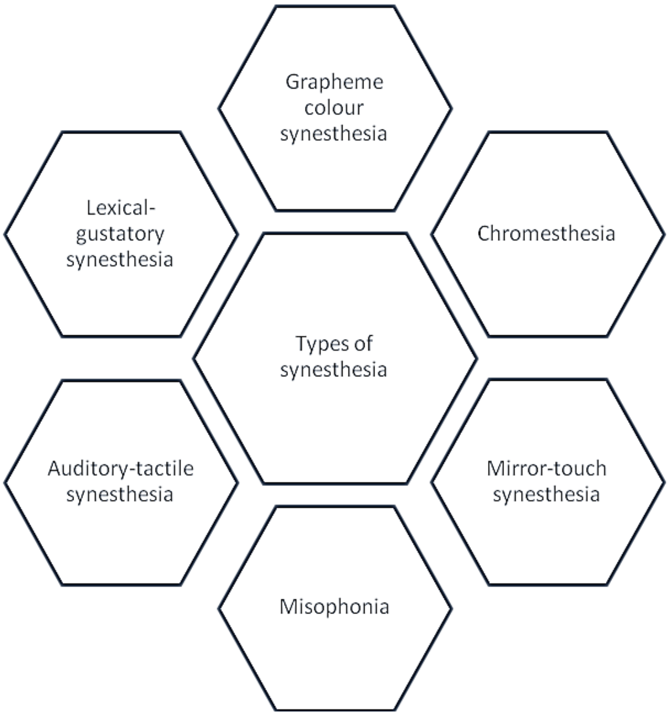

Figure 2. Prevalent patterns of synesthesia. Based on the difference in the sensory perception from one form to another, synesthesia is classified into grapheme-color, lexical-gustatory, auditory-tactile, misophonia, mirror-touch synesthesia and chromesthesia.

b. Chromesthesia

Another common form of synesthesia involves associating sounds with colours. Everyday sounds can trigger colour perceptions, and musical notes or keys can also evoke colours. Some individuals with music-related synesthesia may have perfect pitch, using colour cues to identify notes. These colour experiences triggered by sounds are known as photisms. Chromesthesia, described as "fireworks" by Richard Cytowic, leads to the perception of colours and dynamic shapes in response to voice, music, and environmental sounds. The colours can alter based on sound qualities, and some synesthetes see music projected as lines with depth. Yet, there is limited agreement on the correlation between a specific sound and color, as even famous composers such as Liszt and Rimsky-Korsakov had differing opinions on the hues of musical keys (4).

c. Mirror-touch synesthesia

Mirror-touch synesthesia is a type of synesthesia where people feel the same sensations as others, such as touch. For example, if a synesthete with this form of synesthesia sees someone getting tapped on the shoulder, they will feel a tap on their own shoulder automatically. Individuals with mirror-touch synesthesia typically show higher levels of empathy in comparison to the average population. This connection may be related to mirror neurons located in the motor regions of the brain, which are linked to empathy (3).

d. Misophonia

Misophonia is a condition of the nervous system in which certain sounds can evoke negative emotions of rage, repulsion, or anxiety. It might be linked to synesthesia, involving abnormal connections between auditory and limbic brain regions. While hearing is normal, the limbic system remains highly responsive to sounds. Severe cases could affect cognitive control, and though its cause isn't clear, genetics and additional conditions might play a role. There's no cure, but coping strategies like avoidance, using earplugs, music, or internal dialogue can help manage it (5,7–9).

e. Auditory-tactile synesthesia

Auditory-tactile synesthesia occurs when specific sounds can elicit physical sensations in the body. For instance, hearing a word might feel like a touch in a particular body part, or certain sounds can create skin sensations without physical touch. This is different from the mild reaction called frisson. It's a rare type of synesthesia(10).

f. Lexical gustatory synesthesia

It is an alternative form of synesthesia that relates to experiencing distinct flavors when words are heard. For instance, the word "basketball" could evoke a flavor indicative to waffles. The film 'Derek Tastes of Earwax' is named after the sensation experienced by James Wannerton, a bar owner who connects it with hearing his own name. It is considered one of the most uncommon forms of synesthesia, with approximately 0.2% of individuals with synesthesia experiencing this variation.

g. Sequence-space synesthesia

An internally created visual and/or spatial sensory experiences are the distinctive characteristic of this synesthesia, which shares many perceptual characteristics with non-synesthetic imagery. Thus, we propose that it is by definition a type of visuospatial imagery, and a manifestation of the significant individual variances in mental imagery vividness and frequency in the general population (11).

h. Ticker-tape synesthesia (TTS)

Some people instinctively and vividly see the written form of the words they hear in their minds. Ticker-tape synesthesia (TTS) is a phenomena where speech processing in language areas is assumed to have an abnormally high influence on orthographic representations in the visual cortex (12).

i. Voice-induced synesthesia

The condition known as voice-induced synesthesia, wherein synesthetic perceptions are elicited by the sounds of people's voices, seems to be somewhat uncommon and has not been thoroughly investigated (e.g., falsetto, whisper, and nasal) (13).

j. Musical–space synesthesia

Pitch perception in music is characterised by a perceived spatial array in musical–space synesthesia. The symbolic inducers, such as numerals or months, can modify response based on how they are positioned in relation to the synesthetic spatial form (14).

k. Color -to- taste synesthesia

Although colours are obviously conceptual inducers, in many circumstances it is probably sufficient for the synesthete to only think about the colour in question or possibly hear someone utter its name. The taste sensation is formed when the individual views the colour visually (15).

l. Acquired synesthesia

It is possible to develop acquired synesthesia following brain injury or sensory deafferentation. The concurrent in this kind are typically called phosphenes. A visual phenomena known as a phosphene, or insufficient stimulus to the photoreceptors, can be produced by physically, electrically, magnetically, or directly stimulating the occipital cortex (16).

m. Genuine synesthesia

Genuine synesthesia is believed to arise through "hyper-association" between different brain regions; It is unclear if feedback loops, more sensitive binding mechanisms, are to blame for this "hyper-association," or if it results from a direct cross-activation of the brain regions processing the inducer and the concomitant (17).

n. Drug-induced Synesthesia

When under the acute effects of a hallucinogen (mescaline, psilocybin, LSD), one may experience drug-induced synesthesia. Intoxication is usually accompanied by a dream-like state of consciousness, altered perception of time and cognitive capacities, an increase of affectivity, a decrease in self-control, and changes in the relationship between the sense of self and the cosmic. In addition, a strong Inner stream of sensations is frequently felt in conjunction with hallucinations, particularly in the visual domain (17).

o. Time-space synesthesia

It is, in simple terms, "seeing time." Every instant of time has a significant correlation with a certain location in "space." For example, some people can perceive the months as a circle that surrounds them. For others, the years might represent a loopy, squiggly line, with each decade occupying a certain portion (18).

4. ETIOLOGY

The experience of synesthesia can manifest through three distinct pathways as shown in Figure 3. A subset of the population exhibits developmental synesthesia, wherein synesthetic perceptions or conceptions emerge in early childhood and persist throughout life. The genetic cause of developmental synesthesia is still unknown, but it may be passed down through autosomal dominant or X-linked dominant inheritance patterns.

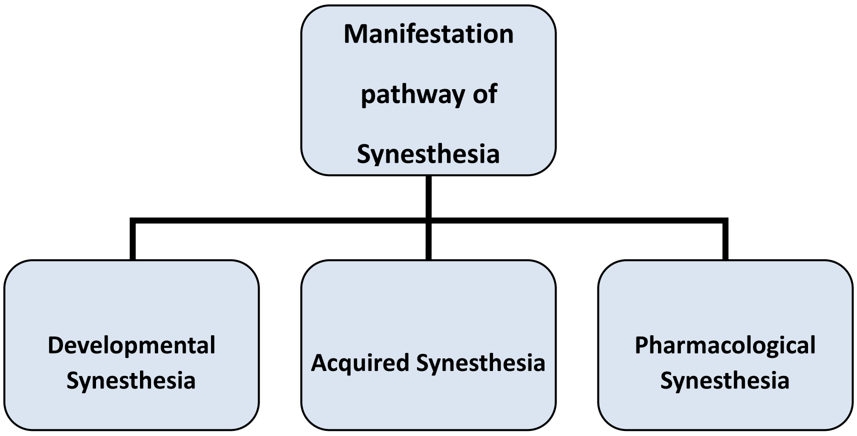

Figure 3. Illustration depicting the three manifestation pathways of Synesthesia.

Alternatively, synesthesia can onset later in life due to brain injuries or sensory deafferentation. This acquired synesthesia, albeit rare, may involve synesthetic perception, and cases of acquired synesthetic conception have not been reported (19).

In addition, the consumption of mescaline or LSD can cause synesthesia pharmacologically while under the influence of the drugs. This state of synesthesia can result in different types of synesthetic experiences that are not seen in developmental synesthesia, but there are no reported cases of pharmacologically induced synesthetic experiences. Investigating physiological and psychological aspects, helps uncover the underlying mechanisms and adds to a theoretical framework for comprehending synesthesia. While certain inducers consistently elicit specific concurrent experiences in an individual, certain forms of synesthesia exhibit varying degrees of flexibility in response to inducer stimuli. For instance, while the letter 'A' may induce a specific red shade, the colour could remain consistent in spite of variations in writing. The mentioned variability raises questions about the characteristics and range of synesthetic triggers(20).

4.1Theories on the pathophysiology of synesthesia

4.1.1 Disinhibition of Feedback:

This mechanism suggests that synesthesia may arise from excess anatomical connections that are normally pruned during development (Figure 4). During typical brain development, certain connections between sensory areas are pruned to ensure efficient processing. However, in individuals with synesthesia, these connections remain intact or are even strengthened. As a result, feedback signals in the brain become disinhibited, allowing for cross-activation between different sensory areas. This cross-activation leads to synesthetic experiences, where stimulation in one sensory modality triggers perceptions in another (20).

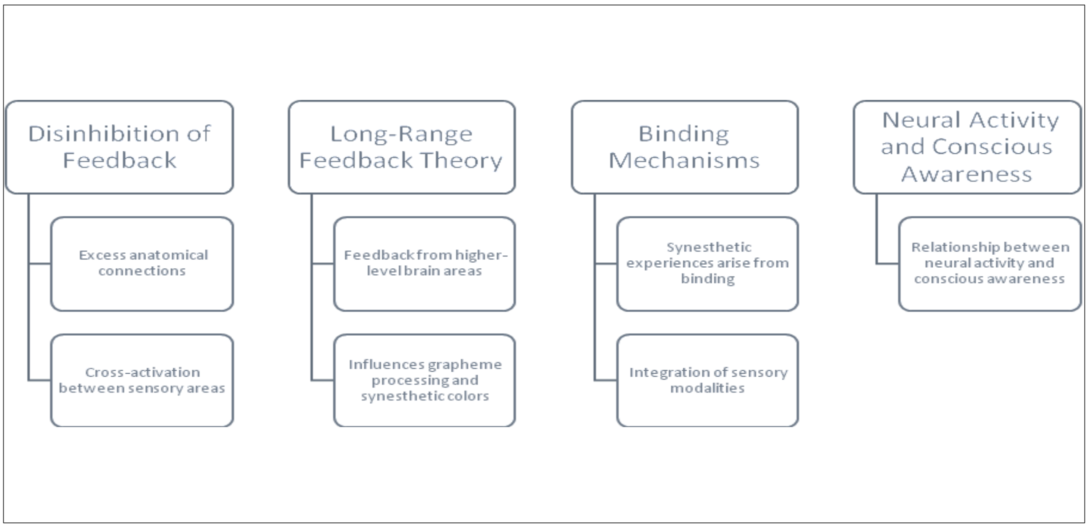

Figure 4. Mechanisms of synesthesia etiology. The various theories of synesthesia providing unique approaches for its etiology.

4.1.2 Long-Range Feedback Theory:

The long-range feedback theory proposes that feedback is a common phenomenon in the visual system and plays a role in modulating synesthetic colours. According to this theory, neural signals propagate back from higher-level brain areas, such as V4 and PIT, to earlier visual processing areas. These feedback signals influence the recognition and processing of graphemes, which are the basic units of written language. As a result, the meaning associated with graphemes can influence the perception of synesthetic colours. For example, seeing the letter "A" may evoke the colour red due to the feedback influence of its meaning (4,20).

4.1.3 Binding Mechanisms Theory

The binding mechanism suggests that synesthetic experiences arise from the binding of different sensory modalities. When a number or word triggers synesthesia, there is a visual image or auditory input that can be associated with the synesthetic perception. For example, when the number "2" is perceived as the colour green, there is a binding between the visual representation of the number and the colour perception. This mechanism highlights the importance of having an object or stimulus for the synesthetic activation to bind to, allowing for the integration of different sensory modalities.

4.1.4 Neural Activity and Conscious Awareness:

This mechanism explores the relationship between neural activity and conscious awareness in synesthesia. It is still an active area of research to understand why certain neural activity associated with synesthetic experiences reaches conscious awareness, while other bidirectional effects may not. Different proposals suggest that activity in early sensory areas or in higher-level brain regions may play a role in determining which synesthetic perceptions become consciously accessible. Further investigation is needed to fully elucidate the neural mechanisms underlying conscious awareness in synesthesia (20).

Experimental evidence supporting the above-mentioned theories has been achieved via functional imaging studies. Using Functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) scans, studies have demonstrated that synesthetes show higher brain region co-activation in response to stimuli that induce their synesthetic perceptions. In grapheme-color synesthetes, not only the visual word form area was activated but the color processing regions are both activated by seeing letters or numbers (21). On the other hand, genetic studies suggest a heritable component to synesthesia, with several familial cases reported. Research indicates that synesthesia might follow a polygenic mode of inheritance, meaning multiple genes could contribute to its development. However, specific genes associated with synesthesia have yet to be conclusively identified (22). Synesthesia is often associated with enhanced memory and perceptual abilities. Synesthetes tend to perform better on memory tasks, likely because their additional sensory experiences provide extra mnemonic cues. Furthermore, synesthesia is linked to increased creativity and the ability to form unusual associations, which can be advantageous in artistic and intellectual pursuits (23).

Despite these potential benefits, synesthesia can also pose challenges. Some synesthetes report sensory overload or difficulty focusing due to the constant bombardment of additional sensory information. These experiences underscore the complexity of the condition and its variable impact on individuals' lives (24).

5. Reviewing the case studies

5.1 Case 1:

The case study, conducted by researchers, focuses on a male individual named John who has been diagnosed with lexical-gustatory synesthesia. John, with an IQ level of 120, reported experiencing taste, texture, and temperature sensations triggered by specific words. The study employed rigorous methodologies, including retesting after three decades, to ensure the authenticity and stability of John's synesthetic experiences (25). The results of the study revealed that approximately 56% of the words presented to John elicited synesthetic flavors. This finding indicates a strong association between language and taste sensations in John's synesthetic perception. The high percentage suggests a consistent and robust cross-modal mapping between linguistic stimuli and gustatory experiences in John's case. The methodology used in the study involved presenting various words to John and recording his synesthetic responses. The retesting after three decades aimed to verify the consistency of John's synesthetic associations over time, providing evidence for the enduring nature of his synesthetic experiences.

These findings have significant implications for our understanding of lexical-gustatory synesthesia. They add to the increasing knowledge about the psycholinguistic aspects of synesthesia and highlight the intricate relationship between language processing and sensory perception in synesthetes like John (4,25).

In conclusion, the case study of John provides valuable insights into the phenomenon of lexical-gustatory synesthesia. The rigorous methodology, including retesting, strengthens the validity of the findings. The results highlight the strong association between language and taste sensations in John's synesthetic perception, contributing to our understanding of synesthesia and its implications for cross-modal associations. As a reviewer, it is important to consider the significance of these findings and their potential impact on the field of synesthesia research (25).

5.2 Case 2:

SP is a 21-year-old woman who doesn't have any major brain problems except for experiencing migraines with aura. Since she was a child, she has struggled with basic math tasks and was diagnosed with "cognitive learning difficulties" specifically related to math. SP discovered that she has synesthesia. This means that when she sees numbers and letters, her brain automatically associates them with certain colors. For example, she might see the number 3 as the color green, the number 4 as purple, and when she multiplies them together (3×4), she sees the result, 12, as the color orange. Because of her synesthesia, SP's understanding of math concepts is influenced by the colors she sees. This has made math more challenging for her. While others might quickly learn that $3 \times 4 = 12$, SP sees it as a color-coded equation ($3 \times 4 = 12$) that takes longer for her to process. This has led to difficulties and anxiety when dealing with math in her daily life.

Positive Response to the Digit-Color Calculator (DCC)

SP tried using a special calculator called the Digit-Color Calculator (DCC). This calculator displays numbers in colors that match her synesthetic experiences. Surprisingly, she had a very positive reaction to it. It seems that the colors helped her perform math tasks better and more comfortably.

The positive response to the DCC could be due to a few different reasons. It might have made math calculations feel easier for her brain, reduced obstacles that were slowing down her thinking, increased her motivation to do math tasks, or even used the psychological effect of colors to help her concentrate better. The Digit-Color Calculator (DCC) works by aligning SP's synesthetic experiences with her cognitive processes. This alignment happens between the colors she sees (due to her synesthesia) and the way her brain thinks. This involves specific parts of her visual system, like the photoreceptors (cells in the eyes that detect light) and neurons in her brain. This alignment process extends to deeper parts of the brain, like the lateral geniculate nucleus (LGN), which is involved in visual processing. Essentially, the DCC connects SP's unique way of perceiving with her way of thinking, using the bridge between colors and numbers to help her with math tasks (26).

5.3 Case 3:

The case study focuses on the phenomenon of grapheme-colorsynesthesia in the Bengali language. The study aims to understand how diacritics affect the color associations of consonant graphemes and to explore the influence of linguistic properties on synesthetic experiences. To conduct the study, the researchers recruited a synesthete named MJ, who is a native bilingual speaker of Bengali and English. MJ participated in a series of experiments to collect data on her grapheme-color associations.

In Experiment 1, MJ was asked to provide her color associations for individual consonant graphemes in Bengali. The researchers found that MJ consistently associated specific colors with each grapheme, suggesting a strong synesthetic experience. Experiment 2 focused on the influence of diacritics on grapheme-color associations. MJ was presented with consonant graphemes both with and without diacritics, and she was asked to provide color associations for each variation. The results showed that the presence of diacritics did not significantly alter MJ's color associations, indicating that diacritics have a minimal impact on synesthetic experiences in Bengali. In Experiment 3, the researchers investigated the potential influence of the history of MJ's language on her grapheme color associations. They hypothesized that MJ's exposure to English may have impacted her connections with graphemes related to Bengal.

However, the results showed that MJ's English associations did not significantly overlap with her Bengali associations, suggesting that her language history did not confound the synesthetic experiences in Bengali. The study also acknowledges some limitations. One limitation is the time-consuming nature of collecting grapheme-color associations for all Bengali graphemes. It would require a significant amount of time for MJ to provide associations for each grapheme multiple times. Furthermore, MJ's ability to speak two languages may have impacted her unique connections between graphemes and colors, possibly complicating the outcomes.

Overall, the case study provides valuable insights into grapheme-color synesthesia in the Bengali language. It highlights the unique features of the writing system in Bengal and emphasizes the necessity of conducting more studies on synesthesia in languages that use non-alphabetic scripts. The study also suggests that synesthetic experiences can provide insights into the relationship between linguistic properties and the way graphemes are represented in the brain (27).

The pathophysiology of synesthesia involves intricate neural mechanisms, including cross-activation and disinhibited feedback between sensory modalities. Genetic and developmental factors contribute to its manifestation, and it is associated with distinct cognitive and perceptual traits. Continued research is essential to further elucidate the neural underpinnings and genetic basis of this fascinating condition.

6. Conclusion

The review article on synesthesia provides a comprehensive exploration of this captivating neurological phenomenon. Synesthesia is characterized by the blending of sensory or cognitive pathways in the brain, resulting in consistent and involuntary experiences in response to various stimuli. The article delves into the various forms of synesthesia, including grapheme-color and sound-color synesthesia, offering insights into the remarkable diversity of synesthetic experiences. It explores how individuals might perceive colors while listening to music or connect certain flavours with words, highlighting the distinctiveness of these sensory combinations. Theoretical explanations for synesthesia are thoroughly examined, including cross-activation, disinhibited feedback, and hyperconnectivity theories. These theories provide valuable frameworks for understanding the neural mechanisms underlying synesthetic perceptions, though the exact mechanisms remain the subject of ongoing research. The genetic basis of synesthesia is discussed, highlighting its heritable component and the identification of candidate genes. The article also acknowledges the potential influence of environmental factors on synesthetic experiences, underscoring the intricate interplay between genetic predisposition and environmental influences. Neurological mechanisms related to synesthesia are explored, focusing on the brain regions involved in sensory processing. This knowledge not only enhances our understanding of synesthesia but also offers insights into related cognitive processes, such as speech and mental imagery. The review article also considers the broader implications of synesthesia, including potential benefits such as enhanced memory and perception, as well as the challenges faced by synesthetes in their daily lives. Real-world case studies are presented to illustrate the impact of synesthesia on individuals. For example, John's experience with lexical-gustatory synesthesia highlights the strong link between language and taste sensations. Additionally, SP's case demonstrates how synesthetic experiences can influence one's understanding of mathematics and how innovative solutions, like the Digit-Color Calculator, can help individuals overcome challenges. A study on grapheme-color synesthesia in the Bengali language underscores the importance of considering linguistic properties when studying synesthesia in diverse cultural and linguistic contexts.

In conclusion, this review serves as a valuable tool for researchers studying the complex relationship between perception, cognition and the human brain. It consolidates existing knowledge while pointing toward promising avenues for future research in the field of synesthesia.

7. REFERENCES

1. Robertson LC, Sagiv N. Synesthesia: Perspectives from cognitive neuroscience. Oxford University Press; 2005.
2. Nikolić D. Is synaesthesia actually ideaesthesia? An inquiry into the nature of the phenomenon. In: Proceedings of the Third International Congress on Synaesthesia. 2009.
3. Heyes C. Where do mirror neurons come from? Neurosci Biobehav Rev. 2010 Mar;34(4):575–83.
4. Ward J. Synesthesia. Annu Rev Psychol. 2013;64:49–75.
5. Edelstein M, Brang D, Rouw R, Ramachandran VS. Misophonia: physiological investigations and case descriptions. Front Hum Neurosci. 2013 Jun 25;7:296.
6. Bankieris K, Simner J. Sound symbolism in synesthesia: evidence from a lexical-gustatory synesthete. Neurocase. 2014;20(6):640–51.
7. Schröder A, van Diepen R, Mazaheri A, Petropoulos-Petalas D, Soto de Amesti V, Vulink N, et al. Diminished n1 auditory evoked potentials to oddball stimuli in misophonia patients. Front Behav Neurosci. 2014 Apr 9;8:123.
8. Daniels EC, Rodriguez A, Zabelina DL. Severity of misophonia symptoms is associated with worse cognitive control when exposed to misophonia trigger sounds. PLoS One. 2020 Jan 16;15(1):e0227118.
9. Duddy DF, Oeding KAM. Misophonia: An Overview. Semin Hear. 2014 May;35(02):084–91.
10. Naumer MJ, van den Bosch JJF. Touching sounds: thalamocortical plasticity and the neural basis of multisensory integration. J Neurophysiol. 2009 Jul;102(1):7–8.
11. Gould C, Froese T, Barrett AB, Ward J, Seth AK. An extended case study on the phenomenology of sequence-space synesthesia. Front Hum Neurosci. 2014 Jul 3;8:433.
12. Hauw F, El Soudany M, Cohen L. The advantage of being a synesthete: The behavioral benefits of ticker-tape synesthesia. Cortex. 2023 Nov;168:226–34.
13. Moos A, Simmons D, Simner J, Smith R. Color and texture associations in voice-induced synesthesia. Front Psychol. 2013 Sep 2;4:568.
14. Bragança GFF, Fonseca JGM, Caramelli P. Synesthesia and music perception. Dement Neuropsychol. 2015 Jan;9(1):16–23.
15. Brang D, Ramachandran VS. Survival of the synesthesia gene: why do people hear colors and taste words? PLoS Biol. 2011 Nov;9(11):e1001205.
16. Afra P, Funke M, Matsuo F. Acquired auditory-visual synesthesia: A window to early cross-modal sensory interactions. Psychology Research and Behavior Management. 2009;31–7.
17. Sinke C, Halpern JH, Zedler M, Neufeld J, Emrich HM, Passie T. Genuine and drug-induced synesthesia: a comparison. Conscious Cogn. 2012 Sep;21(3):1419–34.
18. Brang D, Miller LE, McQuire M, Ramachandran VS, Coulson S. Enhanced mental rotation ability in time-space synesthesia. Cogn Process. 2013 Nov;14(4):429–34.
19. Hubbard EM, Ramachandran VS. Neurocognitive mechanisms of synesthesia. Neuron. 2005 Nov 3;48(3):509–20.

20. Grossenbacher PG, Lovelace CT. Mechanisms of synesthesia: cognitive and physiological constraints. Trends Cogn Sci. 2001 Jan 1;5(1):36–41.
21. Nunn JA, Gregory LJ, Brammer M, Williams SCR, Parslow DM, Morgan MJ, et al. Functional magnetic resonance imaging of synesthesia: activation of V4/V8 by spoken words. Nat Neurosci. 2002 Apr;5(4):371–5.
22. Asher JE, Aitken MR, Farooqi N, Kurmani S, Baron-Cohen S. Diagnosing and phenotyping visual synesthesia: a preliminary evaluation of the revised test of genuineness (TOG-R). Cortex. 2006;42(2):137–46.
23. Rothen N, Meier B, Ward J. Enhanced memory ability: insights from synesthesia. Neurosci Biobehav Rev. 2012;36(8):1952–63.
24. Baron-Cohen S, Harrison J, Goldstein LH, Wyke M. Coloured speech perception: is synaesthesia what happens when modularity breaks down? Perception. 1993;22(4):419–26.
25. Ramachandran VS, Chunharas C, Marcus Z. Constructing calendars in the brain. Neurocase. 2020 Feb;26(1):7–17.
26. Berger JJ, Harris IM, Whittingham KM, Terpening Z, Watson JDG. Substantiating synesthesia: a novel aid in a case of grapheme-colour synesthesia and concomitant dyscalculia. Neurocase. 2020 Feb;26(1):29–35.
27. Root N, Bhattacharyya P, Ramachandran VS. Grapheme-ColorSynesthesia in an Abugida: a Bengali Case Study. Multisensory research. 2020;34(2):187–218.