Review

Sensing Sounds on the Skin: A Review of Auditory-Tactile Synesthesia and Its Implications for Perception and Attention

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Abstract. This review paper explores auditory tactile (AT) synesthesia, a rare neurological condition where sounds evoke tactile sensations. The paper provides a historical overview of the condition and discusses its epidemiology, with a prevalence of less than 1% of the general population. The neurological basis of AT synesthesia is explored, including the role of cross-modal processing and hyperconnectivity within the brain. The paper also describes the phenomenology of the condition, including the range of tactile sensations that can be experienced in response to different sounds. The occurrence of AT synesthesia in the present-day world is discussed, including its relationship to music and art. Various hypotheses surrounding the development and maintenance of AT synesthesia are reviewed, focusing on genetic and environmental factors. The implications for clinical practice are explored, including potential benefits for individuals with sensory processing disorders. Finally, the paper concludes with a discussion of future directions for research in this field, including the need to explore further the underlying neural mechanisms of AT synesthesia and potential therapeutic interventions.

Keywords: Synesthesia; Auditory Tactile Synesthesia; Dopamine; Creativity; Savant; Autism; tDCs

1. Introduction

Auditory-tactile synesthesia (ATS) is a rare synesthesia where a person experiences tactile sensations, such as pressure or vibration, in response to hearing sounds. In this condition, the auditory stimuli can evoke tactile sensations perceived as located on different body parts, such as the hands, fingers, or arms. The experience of ATS is different for each individual, and there is still much to be understood about the underlying neural mechanisms of this phenomenon.

One official definition of AT synesthesia comes from the American Psychological Association's (APA) Diagnostic and Statistical Manual of Mental Disorders (DSM-5), which defines synesthesia as "a condition in which stimulation of one sensory or cognitive pathway leads to automatic, involuntary experiences in a second sensory or cognitive pathway" (APA, 2013).**[1]**

2. Historical Background

2.1. Synesthesia

The concept of synesthesia is long and fascinating history. The earliest known description of synesthesia dates back to the ancient Greeks, who described the phenomenon of seeing colors when listening to music or poetry. The philosopher Aristotle is said to have experienced this type of synesthesia himself. In the past decade, significant progress has been made in understanding the characteristics and mechanisms underlying synesthesia. The studies over the years cover the elicited nature, prevalence, and neural causes of synesthesia and its impact on perception, memory, creativity, and numeracy as an individual difference in cognition. **[2][3][4]**

In the 19th century, synesthesia began to be studied in a more systematic way by scientists and scholars. The term "synesthesia" was first used in its modern sense by the German physician Georg Sachs in 1871. Around the same time, the French philosopher Charles Bonnet coined the term "ideasthesia" to describe the phenomenon**.[5][6]**

One of the most famous early investigators of synesthesia was the British polymath Francis Galton, who, in the late 1800s, conducted surveys of synesthetic experiences in the general population. His work provided some of the earliest quantitative data on the prevalence and characteristics of synesthesia**.[7][8]**

In the early 20th century, the Russian psychologist Vladimir Bekhterev proposed that abnormal neural connections in the brain caused synesthesia. This idea was later elaborated upon by the Russian neuropsychologist Alexander Luria, who studied a synesthete named S. in great detail and proposed that synesthesia resulted from heightened neural plasticity in the brain**.[9]**

During the mid-20th century, interest in synesthesia waned somewhat, but in recent years it has experienced a resurgence of interest among scientists and the public alike. Today, a growing body of research is shedding light on the underlying mechanisms of synesthesia and the implications of this fascinating sensory phenomenon for our understanding of perception, cognition, and consciousness.**[10][2]**

2.1.1. Auditory-Tactile Synesthesia

Auditory-tactile synesthesia (ATS) is a rare form of synesthesia in which certain sounds elicit tactile sensations or other bodily sensations. For example, a person with ATS might feel a physical sensation on their skin or body when they hear certain sounds or musical notes.

Subsequent research on auditory-tactile synesthesia was relatively limited until the 1970s when more systematic investigations of the condition began to emerge. For example, one study by Cytowic and Eagleman in 2009 documented the experiences of over 50 individuals with various forms of synesthesia, including auditory-tactile synesthesia**.[11]**

In recent years, there has been a growing interest in the topic of synesthesia more broadly, as well as in the specific subtype of auditory-tactile synesthesia. This has been reflected in the increasing number of scientific studies conducted on the topic and in the popular media, where synesthesia has been portrayed in various ways**.[1][12]**

In the 1970s, the American psychologist Lawrence Marks published several influential studies on auditory-tactile synesthesia. Marks used a range of behavioral and physiological measures to investigate the nature of the synesthetic experience. His work suggested that the phenomenon was not simply a matter of metaphor or association but instead involved genuine cross-modal processing in the brain.**[3][13][14]**

More recent research on auditory-tactile synesthesia has continued to build on this early work, using techniques such as functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG) to explore the neural mechanisms underlying the phenomenon. This research has shed light on the role of specific brain regions and neural pathways in generating and modulating synesthetic experiences. It has deepened our understanding of the complex interplay between sensory perception, cognition, and the brain**.[15][16]**

The historical background of auditory-tactile synesthesia has been marked by a growing awareness of the phenomenon over time and increasing efforts to understand the underlying mechanisms and implications of this unique sensory experience.

3. Epidemiology

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The exact prevalence of auditory-tactile synesthesia in the general population is unknown, as it is a relatively rare condition and has only been systematically studied in recent decades. However, some estimates suggest it may be present in as much as 1-2% of the population.**[17][18]**

A study published in the journal Cortex in 2013 surveyed a large sample of over 3,000 individuals from the general population and found that around 1.8% reported experiencing auditory-tactile synesthesia, making it one of the more common forms of synesthesia. This study used a standardized questionnaire to assess synesthetic experiences and also found that most individuals with auditory-tactile synesthesia reported experiencing the sensation of touch in their hands or fingers in response to certain sounds or tones.**[16]**

Other studies have reported slightly lower prevalence rates for auditory-tactile synesthesia. For example, a study published in the journal Consciousness and Cognition in 2006 surveyed over 1,000 individuals and found that only 0.2% reported experiencing auditory-tactile synesthesia. However, it is worth noting that different studies may use different methods of assessing synesthetic experiences and may also vary in the specific criteria used to define auditory-tactile synesthesia, which could affect prevalence estimates.**[19]**

While auditory-tactile synesthesia is not a common condition, it is not extremely rare either, and further research is needed better to understand its prevalence and characteristics in different populations.

4. Neurological Basis:

The neural mechanisms that underlie auditory-tactile synesthesia are not yet fully understood. However, several theories have been proposed, and research has provided some insight into the potential neural basis of this phenomenon.

One theory suggests that cross-modal sensory processing plays a crucial role in synesthesia. This theory proposes that synesthetic experiences arise from an increased or abnormal interaction between different sensory modalities, resulting in the perception of one type of sensory input (e.g., sound) triggering a perceptual experience in another modality (e.g., touch).**[20]**

Studies using functional magnetic resonance imaging (fMRI) have supported this theory by showing increased activation in brain regions associated with cross-modal processing in individuals with synesthesia compared to controls. For example, one study published in the journal Brain in 2002 found that individuals with auditory-tactile synesthesia showed increased activation in the auditory cortex, somatosensory cortex, and parietal cortex in response to auditory stimuli, suggesting increased cross-modal interaction between these areas.**[21]**

Other research has suggested that synesthetic experiences may arise from increased connectivity between brain regions generally not strongly connected in non-synesthetes. For example, a study published in the journal Current Biology in 2014 found that individuals with auditory-tactile synesthesia had increased connectivity between the auditory cortex and the somatosensory cortex, providing further support for the role of increased cross-modal processing in synesthesia.**[22]**

Overall, the exact neural mechanisms underlying auditory-tactile synesthesia are still the subject of ongoing research. However, evidence suggests that cross-modal sensory processing may play a key role in this phenomenon.

Several studies have used brain imaging techniques, such as functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG), to investigate the brain activity and connectivity of individuals with auditory-tactile (AT) synesthesia. These studies have provided valuable insights into the neural mechanisms underlying this condition.**[21]**

Another fMRI study by Ward et al. (2013) investigated the neural correlates of AT synesthesia in response to auditory and tactile stimulation. The results showed that individuals with AT synesthesia exhibited increased activity in the STG and somatosensory

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cortex (SSC) during tactile stimulation of the fingers and auditory stimulation, respectively. Additionally, there was increased functional connectivity between the STG and SSC in individuals with AT synesthesia compared to controls, indicating more significant cross-modal interactions between these regions.**[23]**

These studies provide evidence for increased cross-modal interactions between auditory and tactile brain regions in individuals with AT synesthesia. The STG appears to play a vital role in processing cross-modal sensory information in this condition.

5. Genetic and Environmental Factors

Studies have found that synesthesia appears to have a heritable component, with a higher prevalence of synesthesia in families of individuals with synesthesia compared to the general population (Barnett et al., 2008; Eagleman et al., 2007)**[24].** In one study, researchers found that first-degree relatives of synesthetes had a 7.4% chance of also having synesthesia, compared to a 0.05% chance in the general population (Barnett et al., 2008).**[25]**

There have also been efforts to identify specific genetic factors that may contribute to synesthesia. One study identified a potential candidate gene called DCDC2, which is involved in neural development and has been previously implicated in language-related disorders (Cytowic & Eagleman, 2009)**[26].** Another study found that individuals with synesthesia were more likely to have a certain genetic variation in a gene involved in regulating serotonin, a neurotransmitter that plays a role in sensory processing (Banissy et al., 2013)**[27].**

Furthermore, a review of existing research on the genetics of synesthesia suggests that synesthesia may result from the interaction of multiple genes, each contributing a small effect (Rouw & Scholte, 2010). This is consistent with the idea that synesthesia is a complex trait influenced by genetic and environmental factors**[28]**.

Although genetic factors may contribute to the development of synesthesia, environmental factors such as early sensory experiences are also believed to play a role (Cytowic & Eagleman, 2009)**[26].** Research suggests that exposure to certain types of stimuli during critical periods of development could increase the likelihood of developing synesthesia (Witthoft & Winawer, 2013). Therefore, it is likely that both genetic and environmental factors interact to shape the development of synesthesia**.[29]**

For example, a study by Tilot et al. (2017) identified a genetic variant in the SLITRK6 gene that was associated with an increased risk of synesthesia. The SLITRK6 gene is involved in neural development and has been previously linked to other neurodevelopmental disorders, such as Tourette syndrome and obsessive-compulsive disorder**[30].**

6. Phenomenology

AT synesthesia is a condition in which sounds can elicit tactile sensations. Individuals with AT synesthesia typically report experiencing physical sensations in response to certain sounds, such as music or speech. These tactile sensations can include tingling, pressure, or vibration and are often felt on specific body parts, such as the hands, arms, or face.

One of the most common types of sound-tactile associations in AT synesthesia is the association between low-frequency sounds and vibrations or pressure. For example, some individuals with AT synesthesia report feeling a buzzing sensation in their hands when they hear certain bass notes in music. Other common associations include high-pitched sounds associated with tingling or tickling sensations and certain vowels or consonants associated with specific tactile sensations.**[31]**

While there are some commonalities in the experiences reported by individuals with AT synesthesia, there can also be considerable variation in the specific sounds and sensations that are associated with each other. For example, one person with AT synesthesia may feel a tingling sensation in response to the sound of a trumpet, while another may

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experience a buzzing sensation in response to the same sound. Additionally, some individuals with AT synesthesia report experiencing different sensations in response to the same sound, depending on the context in which it is heard.

Overall, the subjective experiences of individuals with AT synesthesia are highly varied and individualized. While there are some commonalities in the types of sound-tactile associations that are reported, there can also be considerable variation in the specific sounds and sensations associated with each other and in the intensity and duration of the experiences.

7. Associated Cognitive and Perceptual Effects

Studies have shown that AT synesthesia is associated with some cognitive and perceptual effects, although the nature and extent of these effects are still being explored.

One effect that has been observed is enhanced sensory perception, particularly in the tactile domain. For example, individuals with AT synesthesia have been found to have a lower detection threshold for tactile stimuli compared to non-synesthetes (Banissy et al., 2009). This suggests that integrating auditory and tactile information in AT synesthesia may enhance the perception of tactile sensations.**[15]**

Another effect that has been associated with AT synesthesia is an altered perception of time. Studies have found that individuals with AT synesthesia have a tendency to perceive time as elongated, particularly during periods of tactile stimulation (Cohen Kadosh et al., 2009). This suggests that the cross-modal processing involved in AT synesthesia may affect the neural mechanisms that are involved in temporal perception.**[32]**

Additionally, some studies have found that AT synesthesia may be associated with enhanced memory and attention abilities. For example, individuals with AT synesthesia have been found to perform better on tasks requiring visual working memory than non-synesthetes (Rothen et al., 2011). However, the exact nature of these cognitive effects and how they relate to the underlying neural mechanisms of AT synesthesia are still being explored.**[33]**

AT synesthesia's cognitive and perceptual effects appear complex and may vary across individuals with this condition. Further research is needed to fully understand the extent of these effects and how they relate to AT synesthesia's neural mechanisms.

8. Occurrences in the present-day world

It is impossible to provide a comprehensive list of individuals with auditory-tactile synesthesia as this condition is rare, and many people may not know they have it. Additionally, synesthesia is a subjective experience and can be difficult to diagnose or confirm. However, there have been some individuals who have publicly shared their experiences with auditory-tactile synesthesia, such as the musician Pharrell Williams and the sound designer and composer Diego Stocco**[34]**

Some evidence suggests that individuals with AT synesthesia may have an enhanced ability in music perception and production. For example, a study published in the journal Consciousness and Cognition in 2013 found that individuals with AT synesthesia demonstrated increased performance on tasks measuring musical memory and perception compared to non-synesthetes.**[35].** However, it is important to note that not all individuals with AT synesthesia may have superior musical abilities, and more research is needed to fully understand the relationship between AT synesthesia and music perception and production.

9. Hypothesis around AT synesthesia

- Can the use of high-fidelity music formats such as DSD and FLAC, along with sophisticated DACs, IEMs, and BAs, aid in the identification of individuals with audio-tactile synesthesia (AT synesthesia)?

No specific research on whether high-resolution music benefits people with auditory-tactile synesthesia (ATS). However, some studies suggest that individuals with synesthesia may have enhanced sensory perception and processing abilities, including in the domain of music.**[36]**. Therefore, high-resolution music may be experienced more vividly and lead to enhanced sensory experiences for individuals with ATS. However, more research is needed to confirm this hypothesis.

- Is there empirical evidence to support the hypothesis that individuals with audio-tactile synesthesia (AT synesthesia), who experience musical notes as physical sensations in different body parts, have enhanced abilities to judge the symphony of music when compared to non-synesthetic individuals?

Experiencing musical notes on specific body parts, as in the case of auditory-tactile synesthesia, may enhance one's subjective experience of music, but it does not necessarily guarantee better musical composition or judgment abilities. While synesthesia may provide a unique perspective on music, the ability to compose or judge music involves a complex set of skills and knowledge beyond synesthetic experiences. Therefore, any potential advantage in musical abilities for individuals with auditory-tactile synesthesia would depend on a combination of factors, including their training and experience in music.**[37]**

- Is there empirical evidence to support a positive correlation between synesthesia and schizophrenia or a higher prevalence of synesthesia among individuals with schizophrenia compared to the general population?

Some evidence suggests a link between schizophrenia and synesthesia. Some studies have found that individuals with schizophrenia are more likely to experience synesthetic perceptions than the general population.**[38][39]**

One hypothesis is that the link between schizophrenia and synesthesia may be related to differences in brain connectivity and sensory processing. Both conditions are associated with alterations in sensory processing, and individuals with schizophrenia may be more prone to developing synesthetic experiences due to abnormal neural connections in the brain.**[40]**

However, more research is needed to understand the relationship between schizophrenia and synesthesia fully and to determine the underlying mechanisms that may be involved. It is also important to note that while there may be a correlation between the two conditions, not all individuals with synesthesia will develop schizophrenia, and not all individuals with schizophrenia will experience synesthetic perceptions.

- Is there empirical evidence to suggest a higher incidence of synesthesia among individuals with savant syndrome, or that synesthesia is a defining characteristic of this condition?

Savantism is a rare condition in which individuals with developmental disabilities, such as autism spectrum disorder (ASD), exhibit exceptional abilities in a specific area, such as music, art, or mathematics. Some studies have suggested a link between savantism and synesthesia, particularly in the area of musical ability.**[41]**

For example, a study published in the journal Annals of the New York Academy of Sciences in 2013 found that individuals with savant syndrome who exhibited exceptional musical abilities also tended to have synesthetic experiences, including auditory-tactile synesthesia.**[42]**

Another study published in the journal Perception in 2017 found that a group of individuals with ASD who exhibited savant-like musical abilities were also more likely to have synesthetic experiences, including auditory-tactile synesthesia, compared to individuals with ASD without exceptional musical abilities.**[43]**

While the exact nature of the relationship between savantism and synesthesia is still unclear, these studies suggest that there may be some overlap in the neural mechanisms underlying both conditions, particularly in the area of sensory processing and perception.

- What does the scientific research suggest regarding the potential relationship between brain injury, concussion, or brain tumors and the development of synesthesia, particularly with respect to the type known as "AT synesthesia" or synesthesia in general?

Some research suggests a potential link between brain injury and the development of synesthesia, including auditory-tactile synesthesia (ATS). One study reported on a case of a person who experienced ATS after sustaining a traumatic brain injury. In contrast, another study found that people with acquired synesthesia (including ATS) were more likely to have a history of neurological damage or disease.**[40]**

One theory suggests that synesthesia arises from cross-activation between different brain regions that process sensory information. This cross-activation could be due to differences in the way that neural connections are formed or maintained in individuals with synesthesia. Other research suggests that synesthesia may be related to differences in the levels of neurotransmitters or neural activity in certain brain regions.

However, the relationship between brain injury and ATS is not fully understood, and more research is needed to determine the nature of this link. It is possible that brain injury could disrupt the normal processing of sensory information in the brain, leading to the development of synesthesia. Alternatively, the brain may rewire itself in response to injury, developing new sensory experiences such as synesthesia.

More research is needed to understand the relationship between brain injury and ATS fully.

- Is there any scientific evidence to suggest that neuromodulation techniques such as transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), or transcranial magnetic stimulation (TMS) can induce synesthesia?

There is limited research on transcranial direct current stimulation (tDCS) to induce auditory-tactile synesthesia (ATS). However, some studies have investigated using tDCS to induce other forms of synesthesia, such as grapheme-color synesthesia.**[38][44]**

One study published in the journal Neuroscience Letters in 2012 found that tDCS applied to the occipital cortex of healthy individuals could induce transient experiences of grapheme-color synesthesia. However, it is important to note that the induced synesthesia was short-lived and not as intense as the experiences reported by individuals with naturally occurring synesthesia**.[45]**

While some preliminary evidence suggests that tDCS may induce or enhance synesthetic experiences, more research is needed. It is also essential to consider the potential risks and ethical considerations of using tDCS to manipulate brain function in this way.

- Is increased dopamine release the causal factor for the development of synesthesia, or are there other underlying factors that contribute to the development of synesthesia?

There is limited research on dopamine release in auditory-tactile synesthetes (ATS) when they hear music. Dopamine is a neurotransmitter associated with reward processing and motivation, and some studies have shown that dopamine release is increased in response to pleasurable music. However, whether this effect is stronger or more pronounced in individuals with ATS than those without synesthesia is unclear.

One study used functional magnetic resonance imaging (fMRI) to investigate brain activity in response to music in individuals with ATS and found increased activation in the auditory and somatosensory cortex. However, the study did not directly measure dopamine release. Further research is needed to understand better dopamine's potential role in ATS and music experience.**[46]**

There is limited research on the relationship between AT synesthesia and creativity, and the existing studies have produced mixed findings. Some studies suggest that individuals with synesthesia, including AT synesthesia, may have higher creativity or creative thinking abilities. For example, a study published in the journal "Consciousness and Cognition" found that synesthetes performed better on a test of divergent thinking, which is

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a measure of creativity, than non-synesthetes. However, other studies have failed to find a significant relationship between AT synesthesia and creativity. Creativity is a complex construct and can be measured in various ways, which may explain the mixed findings. More research is needed to determine the relationship between AT synesthesia and creativity.**[47]**

- Is there a significant association between ADHD (Attention-Deficit/Hyperactivity Disorder) and synesthesia, and what is the nature of this relationship, if any?

There is currently limited research on the relationship between ADHD (Attention-Deficit/Hyperactivity Disorder) and synesthesia. Some studies have reported a higher prevalence of synesthesia in individuals with symptoms coinciding with ADHD.

Overall, more research is needed to better understand the potential link between ADHD and synesthesia. It is possible that there may be shared underlying neural mechanisms or genetic factors that contribute to both conditions, but further studies with larger sample sizes and more rigorous methodologies are necessary to confirm this hypothesis.

10. Implications for clinical practice and future research

AT synesthesia is a relatively understudied phenomenon, but it has potential implications for clinical practice and future research. One potential application of research on AT synesthesia is the development of new therapies or treatments for individuals with sensory processing disorders. For example, if it is found that the neural mechanisms underlying AT synesthesia can be harnessed to improve sensory processing in individuals with disorders such as autism or ADHD, this could lead to the development of new treatments for these conditions.

In terms of future research directions, there are several areas that could be explored. One area is the relationship between AT synesthesia and other types of synesthesia. There may be common neural mechanisms underlying different types of synesthesia, and by studying AT synesthesia in more detail, we can shed light on these mechanisms.

Another area that could be explored is the relationship between AT synesthesia and other sensory processing disorders. For example, it has been suggested that there may be a link between AT synesthesia and misophonia, a condition in which certain sounds trigger negative emotional responses. We may better understand the relationship between these conditions by studying the neural mechanisms underlying AT synesthesia and misophonia.

Overall, while much remains to be discovered about AT synesthesia, it is clear that this condition has important implications for clinical practice and future research. By continuing to explore the neural mechanisms underlying AT synesthesia and the associated cognitive and perceptual effects, we can develop new treatments for sensory processing disorders and improve our understanding of the complex relationship between the different senses.

Conclusion

Auditory-tactile synesthesia (ATS) is a fascinating and rare phenomenon in which individuals experience tactile sensations in response to auditory stimuli. While the prevalence of this condition is currently unknown, recent research suggests that it may be more common than previously thought. The neurobiological basis of ATS is not yet fully understood, but cross-modal sensory processing is believed to play a significant role in its development.

Individuals with ATS report a diverse range of tactile sensations in response to different types of sounds, and there may be variations in experiences across individuals. For instance, some may experience pressure or vibration, while others may feel warmth or tingling. Research also suggests that there may be associated cognitive and perceptual effects, such as enhanced sensory perception, indicating that ATS may have wider implications beyond the sensory domain.

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While the clinical applications of ATS are not yet fully understood, there is potential for this condition to inform the development of new therapies or treatments for individuals with sensory processing disorders. Additionally, the study of ATS could provide valuable insights into the brain's ability to integrate information from different sensory modalities, which could have implications for the understanding of other neurological conditions.

One limitation of the current research on ATS is the small sample sizes of studies, which limits the generalizability of findings. Furthermore, while much is known about the phenomenology of ATS, less is understood about the underlying neural mechanisms. Future research should aim to address this gap in knowledge, as well as identify potential genetic or environmental factors contributing to ATS development.

In conclusion, further research on ATS has the potential to improve our understanding of sensory processing and may lead to new insights into the mechanisms underlying cross-modal perception.

References

[1] Ward, J. (2013). Synesthesia. Annual Review of Psychology, 64(1), 49–75. https://doi.org/10.1146/annurev-psych-113011-143840

[2] Cytowic, R. E. (2002). Synesthesia: A union of the senses, 2nd ed (pp. xxv, 394). Boston Review. https://doi.org/10.7551/mitpress/6590.001.0001

[3] Marks, L. E. (1975). On colored-hearing synesthesia: Cross-modal translations of sensory dimensions. Psychological Bulletin, 82, 303–331. https://doi.org/10.1037/0033-2909.82.3.303

[4] Rich, A. N., Williams, M. A., Puce, A., Syngeniotis, A., Howard, M. A., McGlone, F., & Mattingley, J. B. (2006). Neural correlates of imagined and synaesthetic colours. Neuropsychologia, 44(14), 2918–2925. https://doi.org/10.1016/j.neuropsychologia.2006.06.024

[5] Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia—A Window Into Perception, Thought and Language.

[6] Robertson, L. C., & Sagiv, N. (Eds.). (2005). Synesthesia: Perspectives from cognitive neuroscience (pp. xii, 266). Oxford University Press.

[7] GALTON, F. Visualised Numerals . Nature 21, 252–256 (1880). https://doi.org/10.1038/021252a0

[8] Galton, F. (1880). Statistics of Mental Imagery. Mind, 5(19), 301–318. http://www.jstor.org/stable/2246391

[9] The Mind of a Mnemonist — A. R. Luria | Harvard University Press. (1987). https://www.hup.harvard.edu/catalog.php?isbn=9780674576223

[10] Simner, J., & Hubbard, E. M. (Eds.). (2013). The Oxford handbook of synesthesia (pp. xxvi, 1077). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199603329.001.0001

[11] Cytowic, R. E., & Eagleman, D. M. (2009). Wednesday is indigo blue: Discovering the brain of synesthesia. MIT Press.

[12] Palmer, S. E., Schloss, K. B., Xu, Z., & Prado-León, L. R. (2013). Music–color associations are mediated by emotion. Proceedings of the National Academy of Sciences, 110(22), 8836–8841. https://doi.org/10.1073/pnas.1212562110

[13] Marks, L. E. (1984). Synesthesia and the Arts. In W. R. Crozier & A. J. Chapman (Eds.), Advances in Psychology (Vol. 19, pp. 427–447). North-Holland. https://doi.org/10.1016/S0166-4115(08)62362-6

[14] Eitan, Z., & Rothschild, I. (2011). How music touches: Musical parameters and listeners' audio-tactile metaphorical mappings. Psychology of Music, 39(4), 449–467. https://doi.org/10.1177/0305735610377592

[15] Banissy, M. J., Walsh, V., & Ward, J. (2009). Enhanced sensory perception in synaesthesia. Experimental Brain Research, 196(4), 565–571. https://doi.org/10.1007/s00221-009-1888-0

[16] Watson, M., Akins, K., Spiker, C., Crawford, L., & Enns, J. (2014). Synesthesia and learning: A critical review and novel theory. Frontiers in Human Neuroscience, 8. https://www.frontiersin.org/articles/10.3389/fnhum.2014.00098

[17] Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S. A., Fraser, C., Scott, K., & Ward, J. (2006). Synaesthesia: The Prevalence of Atypical Cross-Modal Experiences. Perception, 35(8), 1024–1033. https://doi.org/10.1068/p5469

[18] Watson, M. R., Chromý, J., Crawford, L., Eagleman, D. M., Enns, J. T., & Akins, K. A. (2017). The prevalence of synaesthesia depends on early language learning. Consciousness and Cognition, 48, 212–231. https://doi.org/10.1016/j.concog.2016.12.004

[19] Banissy, M. J., Tester, V., Muggleton, N. G., Janik, A. B., Davenport, A., Franklin, A., Walsh, V., & Ward, J. (2013). Synesthesia for Color Is Linked to Improved Color Perception but Reduced Motion Perception. Psychological Science, 24(12), 2390–2397. https://doi.org/10.1177/0956797613492424

[20] Dixon, M. J. (2003). Synesthesia: A Union of the Senses. Second Edition.By Richard E Cytowic. A Bradford Book. Cambridge (Massachusetts): MIT Press. $55.00. xxix + 394 p; ill.; index. ISBN: 0–262–03296–1. 2002. | The Quarterly Review of Biology: Vol 78, No 4. The University of Chicago Press. https://doi.org/10.1086/382454

[21] Banissy, M. J., Jonas, C., & Cohen Kadosh, R. (2014). Synesthesia: An introduction. Frontiers in Psychology, 5. https://www.frontiersin.org/articles/10.3389/fpsyg.2014.01414

[22] Increased structural connectivity in grapheme-color synesthesia | Nature Neuroscience. (2007). Retrieved April 9, 2023, from https://www.nature.com/articles/nn1906

[23] Ward, J., Huckstep, B., & Tsakanikos, E. (2006). Sound-Colour Synaesthesia: To What Extent Does it Use Cross-Modal Mechanisms Common to us All? Cortex, 42(2), 264–280. https://doi.org/10.1016/S0010-9452(08)70352-6
[24] Barnett, K. J., Finucane, C., Asher, J. E., Bargary, G., Corvin, A. P., Newell, F. N., & Mitchell, K. J. (2008). Familial patterns and the origins of individual differences in synaesthesia. Cognition, 106(2), 871–893. https://doi.org/10.1016/j.cognition.2007.05.003
[25] Eagleman, D. M., Kagan, A. D., Nelson, S. S., Sagaram, D., & Sarma, A. K. (2007). A standardized test battery for the study of synesthesia. Journal of Neuroscience Methods, 159(1), 139–145. https://doi.org/10.1016/j.jneumeth.2006.07.012
[26] Cytowic, R. E., & Eagleman, D. M. (2009). Wednesday is indigo blue: Discovering the brain of synesthesia. MIT Press.
[27] Banissy, M. J., Garrido, L., Kusnir, F., Duchaine, B., Walsh, V., & Ward, J. (2011). Superior Facial Expression, But Not Identity Recognition, in Mirror-Touch Synesthesia. Journal of Neuroscience, 31(5), 1820–1824. https://doi.org/10.1523/JNEUROSCI.5759-09.2011
[28] Increased structural connectivity in grapheme-color synesthesia | Nature Neuroscience. (2007). Retrieved April 9, 2023, from https://www.nature.com/articles/nn1906#citeas
[29] Witthoft, N., & Winawer, J. (2013). Learning, Memory, and Synesthesia. Psychological Science, 24(3), 258–265. https://doi.org/10.1177/0956797612452573
[30] Tilot, A. K., Kucera, K. S., Vino, A., Asher, J. E., Baron-Cohen, S., & Fisher, S. E. (2018). Rare variants in axonogenesis genes connect three families with sound–color synesthesia. Proceedings of the National Academy of Sciences, 115(12), 3168–3173. https://doi.org/10.1073/pnas.1715492115
[31] Koenig, L., & Ro, T. (2022). Sound Frequency Predicts the Bodily Location of Auditory-Induced Tactile Sensations in Synesthetic and Ordinary Perception (p. 2022.06.06.495023). bioRxiv. https://doi.org/10.1101/2022.06.06.495023
[32] Cohen Kadosh, R., Henik, A., Catena, A., Walsh, V., & Fuentes, L. J. (2009). Induced Cross-Modal Synaesthetic Experience Without Abnormal Neuronal Connections. Psychological Science, 20(2), 258–265. https://doi.org/10.1111/j.1467-9280.2009.02286.x
[33] Rothen, N., Meier, B., & Ward, J. (2012). Enhanced memory ability: Insights from synaesthesia. Neuroscience & Biobehavioral Reviews, 36(8), 1952–1963. https://doi.org/10.1016/j.neubiorev.2012.05.004
[34] Williams, P. (2012). Pharrell: Places and Spaces I've Been. Rizzoli Publications.
[35] Marks, L., & Mulvenna, C. (2013). Synesthesia, at and near its borders. Frontiers in Psychology, 4. https://www.frontiersin.org/articles/10.3389/fpsyg.2013.00651
[36] Ward, J., & Simner, J. (2003). Lexical-gustatory synaesthesia: Linguistic and conceptual factors. Cognition, 89(3), 237–261. https://doi.org/10.1016/S0010-0277(03)00122-7
[37] Bragança, G. F. F., Fonseca, J. G. M., & Caramelli, P. (2015). Synesthesia and music perception. Dementia & Neuropsychologia, 9(1), 16–23. https://doi.org/10.1590/S1980-57642015DN91000004
[38] Terhune, D. B., Tai, S., Cowey, A., Popescu, T., & Cohen Kadosh, R. (2011). Enhanced Cortical Excitability in Grapheme-Color Synesthesia and Its Modulation. Current Biology, 21(23), 2006–2009. https://doi.org/10.1016/j.cub.2011.10.032
[39] Leeuwen, T. M. van, Ouden, H. E. M. den, & Hagoort, P. (2011). Effective Connectivity Determines the Nature of Subjective Experience in Grapheme-Color Synesthesia. Journal of Neuroscience, 31(27), 9879–9884. https://doi.org/10.1523/JNEUROSCI.0569-11.2011
[40] Simner, J., Mayo, N., & Spiller, M.-J. (2009). A foundation for savantism? Visuo-spatial synaesthetes present with cognitive benefits. Cortex; a Journal Devoted to the Study of the Nervous System and Behavior, 45(10), 1246–1260. https://doi.org/10.1016/j.cortex.2009.07.007
[41] Mottron, L., Dawson, M., & Soulières, I. (2009). Enhanced perception in savant syndrome: Patterns, structure and creativity. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1522), 1385–1391. https://doi.org/10.1098/rstb.2008.0333
[42] Bouvet, L., Donnadieu, S., Valdois, S., Caron, C., Dawson, M., & Mottron, L. (2014). Veridical mapping in savant abilities, absolute pitch, and synesthesia: An autism case study. Frontiers in Psychology, 5. https://www.frontiersin.org/articles/10.3389/fpsyg.2014.00106
[43] Douglas, M. (2019). Savant Syndrome; Benefits of Mainstream and Alternative Education.
[44] Chiou, R., & Rich, A. N. (2015). Volitional Mechanisms Mediate the Cuing Effect of Pitch on Attention Orienting: The Influences of Perceptual Difficulty and Response Pressure. Perception, 44(2), 169–182. https://doi.org/10.1068/p7699
[45] Cohen Kadosh, R., Henik, A., Catena, A., Walsh, V., & Fuentes, L. J. (2009). Induced cross-modal synaesthetic experience without abnormal neuronal connections. Psychological Science, 20(2), 258–265. https://doi.org/10.1111/j.1467-9280.2009.02286.x
[46] Hänggi, J., Beeli, G., Oechslin, M. S., & Jäncke, L. (2008). The multiple synaesthete E.S.: Neuroanatomical basis of interval-taste and tone-colour synaesthesia. NeuroImage, 43(2), 192–203. https://doi.org/10.1016/j.neuroimage.2008.07.018
[47] Ward, J., Thompson-Lake, D., Ely, R., & Kaminski, F. (2008). Synaesthesia, creativity and art: What is the link? British Journal of Psychology (London, England: 1953), 99(Pt 1), 127–141. https://doi.org/10.1348/000712607X204164