Music & Synesthesia: An Exploration of Synesthesia and its Relation to Musical Perception

Raquel Sierra Johnson

Conservatory of Music, University of the Pacific

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Professor Kyle Bruckmann

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Abstract

This research investigates synesthesia and its impact on musical perception. Synesthesia is the multimodal sensory phenomenon in which the stimulation of one sensory modality generates the experience of a second, otherwise unrelated sense. Discussed topics include: a description of synesthesia and its neurophysiological and perceptual characteristics, the historical conceptualization and documentation of synesthesia beginning with the ancient Greeks, and present-day scientific inquiry. This research explores three varying types of auditory synesthesia - chromesthesia (sound-to-color synesthesia), auditory-tactile synesthesia, and sound-gustatory/sound-olfactory synesthesia - and their multimodal sensory characteristics in relation to music. Prominent neurophysiological hypotheses regarding the existence of synesthesia are examined, compared, and contrasted; these hypotheses include V.S. Ramachandran and E.M. Hubbard's hyperconnectivity feedback theory, P.G. Grossenbacher and C.T. Lovelace's disinhibited feedback theory, and M.R. Watson et al.'s environmentally-acquired theory. The synesthetic experiences of two notable musicians with chromesthesia - twentieth-century modernist composer Olivier Messiaen and pop singer/songwriter Lorde - are discussed to exhibit the influence of synesthesia on a musician's creative output.

Keywords: Synesthesia, multimodal perception, sensation and perception, music, chromesthesia, neurophysiology, hyperconnectivity feedback theory, disinhibited feedback theory, Olivier Messiaen, Lorde

Introduction

The human sensory nervous system possesses five exteroceptive senses that respond to external stimuli: the auditory, visual, olfactory (smell), gustatory (taste), and somatosensory (touch) senses. While each sensory modality maintains its functional independence from the other senses, many of our daily percepts are multimodal sensory experiences - the simultaneous activation of two senses in response to a stimulus. A compelling example of typical multimodal sensation is the concept of taste. Without our olfactory functions, humans' sense of flavor via the gustatory sense is limited to five distinct tastes: sweet, sour, salty, bitter, and savory/umami; the combination of our gustatory and olfactory senses allows for our enhanced sense of flavor beyond the five foundational tastes (Molnar & Gair, 2015). While multimodal sensations are neurotypical and imperative to humans' everyday percepts, what happens when the brain, upon perceiving a stimulus, responds with the activation of an unrelated sensory modality? This unusual multimodal phenomenon is called synesthesia.

Synesthesia describes the neurosensory phenomenon in which the perception of one sensory modality directly causes the conscious experience of an otherwise unrelated sensory attribute (Ward, 2013). "Neurosensory" denotes synesthesia as a phenomenon relating to the sensory activity of the nervous system. While synesthesia was previously thought to occur at a 0.05% rate with higher prevalence in females (Watson et al., 2017), more recent studies depict a 1-4% incidence with weak to no sex prevalence (Bargary & Mitchell, 2008). Some estimates even place the occurrence of synesthesia for every one in twenty-four individuals (Sacks, 2008). Individuals with synesthesia are appropriately called "synesthetes" (Ward, 2013).

Etymologically, “synesthesia” stems from two Greek words: *syn,* meaning “union,” and *aesthesis*, meaning “sensation.” “Synesthesia” thus translates to “a union of the senses” (Cytowic, 2002).

Synesthetic perceptions are automatic, involuntary, and consistent throughout the individual’s life. Those born with synesthesia report experiencing synesthesia for as long as they can remember (Cytowic, 2002). Synesthesia can be idiopathically developed, acquired after a form of sensory loss, or temporarily induced by pharmaceutical and/or hallucinogenic drugs (Ward, 2013; Grossenbacher & Lovelace, 2001). Many synesthetes are unaware that their synesthetic experiences are uncommon and become shocked upon learning that others do not experience the same perceptual phenomenon (Grossenbacher & Lovelace, 2001).

Synesthesia is a unidirectional, multimodal perceptive process between an inducer-concurrent pairing (Bagary & Mitchell, 2008; Ward, 2013). The term “inducer” refers to the original stimulus, while “concurrent” describes the resulting synesthetic experience. The inducer-concurrent pairing occurs simultaneously, and the experience of the concurrent does not replace or diminish the perception of the inducer (Ward, 2013). The inducer that a synesthete is sensitive to will always instigate the concurrent percept. Unidirectionality of synesthetic experiences denotes that the inducer triggers the concurrent, but the concurrent does not trigger the inducer. For example, the letter ‘A’ can induce the color red, but seeing the color red does not induce the perception of ‘A.’ Concurrents are highly individualized, and it is highly unlikely that two synesthetes will share the same inducer-concurrent associations (Grossenbacher & Lovelace, 2001).

Historical Implications & Documentation of Synesthesia

Until the rise of modern-day psychology in the late nineteenth century and scientific medical advancements in the late twentieth century, synesthetic research was marked by a vast history of educated conceptualization and speculation. Although the synesthetic phenomenon had no official name until the late nineteenth century, the conceptualization of synesthesia originates from ancient Greece in the sixth century B.C.E. The Pythagorean sect, followers of the teachings of Pythagoras, attempted to pair particular musical notes with certain colors. The Pythagoreans also conceptualized the "music of the spheres," theorizing that the positions and rotational behavior of celestial bodies worked in tandem to create universal harmony. Over a century later, Aristotle famously promoted the idea of the five distinct senses, but also entertained the existence of a "harmony of colors" that are paired with a corresponding "harmony of sounds" (Gorvetzian, 2013).

Intellectuals of the Enlightenment period (1685-1815) also entertained the idea that color perception may not solely be sourced from light or vision. Isaac Newton theorized a law of physics that correlated colors of the visible light spectrum to the seven intervals in the musical octave scale (Ward, 2013).

The first official documentation of synesthesia occurred in an 1812 medical dissertation by the Austrian doctor George Sachs analyzing his and his sister's albinism. Within his dissertation, Sachs also mentioned his experience with grapheme-color synesthesia (Ward, 2013). Sachs referred to his synesthetic percepts as *phenomena* ("features"), *obscura repraesentatio* ("obscure ideas"), and *ipsam repraesentationem coloratam videri* ("that a colored idea appeared to him") (Jewanksi et al., 2020). In 1848, the French doctor Charles-Auguste-Édouard Cornaz (1825-1911) rediscovered Sach's dissertation and began researching synesthesia from a medical perspective. Cornaz theorized that synesthesia was caused by an extra color receptor in the visual system (Ward, 2013). Cornaz named the phenomenon *hyperchromatopsie* ("perception of too many colors") (Jewanksi et al., 2020). Cornaz's research revealed that it was an idea alone that induced the concurrent perception rather than a misperception, illusion, or biological difference. Cornaz's studies reignited interest in synesthetic research, bringing about new case studies denoting synesthesia as a neurological phenomenon rather than a biological phenomenon (Ward, 2013).

Case studies of synesthesia continued into the nineteenth century with Paul Eugen Bleuler (1857-1939) and Karl Bernhard Lehmann (1858-1940) who began researching synesthesia as twenty-year old medical students in Switzerland. Bleuler had grapheme-color synesthesia and began to engage in synesthetic inquiries of his own family, many of whom were synesthetes. By autumn 1878, Bleuler and Lehmann expanded their studies beyond Bleuler's family and grapheme-color synesthesia, interviewing a total of 596 people with various types of synesthesia - the largest synesthesia study at the time. The duo emphasized the consistency of synesthetic experiences, the commonalities of combined inducers and concurrents, and synesthetes' repeated usage of metaphorical language to describe their concurrent experiences (Jewanksi et al., 2019).

In 1889, the first International Conference of Physiological Psychology hosted the first international symposium on synesthesia in Paris, France. Nearly 400 scientists of various scientific backgrounds were present at the symposium, which served as a contributing factor encouraging further research into synesthesia (Jewanksi et al., 2019).

Mary Whiton Calkins, an American philosopher and psychologist, coined the term "*synæsthesia*" in her 1895 article regarding the subject (Jewanski et al., 2020), arguing that synesthesia is the result of both biological and environmental factors. Calkins was the first researcher to use the word "synesthesia" to describe the wide range of synesthetic experiences; in the present day, researchers continue to utilize the term "synesthesia" in the same fashion (Jewanski et al., 2019).

After multiple decades of scientific neglect, studies focusing on the neurophysiological and genetic causes of synesthesia reignited with Richard Cytowic, an American neurologist, in the 1980s (Watson et al., 2017). Cytowic performed the first neurophysiological studies regarding synesthesia: he hypothesized that synesthesia is the result of multimodal activation in the cerebral cortex, which was proved correct by fMRI imaging of synesthetes' brain activity. Cytowic's subsequent book *Synesthesia: A Union of the Senses* (1989) became highly influential, igniting a new interest in synesthetic research that continues in the present day (Sacks, 2008).

Types of Auditory Synesthesia

Scientific inquiry of synesthesia documents numerous subtypes of the multimodal phenomenon, with some of the more common synesthetic experiences occurring from auditory inducers. One of the most common and documented types of auditory synesthesia is sound-to-color synesthesia, also known as chromesthesia, where a auditory stimulus evokes the sensation of color (Akiva-Kabiri et al., 2014; Shapiro, 2022). Chromesthetic concurrents can also present themselves as shapes, textures, and among different spatial locations in the synesthete's line of sight (Curwen, 2018). Although every synesthete maintains different concurrent associations, chromesthetes share similar experiential principles: higher-pitched sounds appear smaller, brighter, and spatially higher in the visual plane in comparison to lower-pitched sounds (Ward, 2013). For Western synesthetes, the visual musical concurrents transverse from left to right, similar to that of reading a book in a Western language or sheet music (Ward, 2013).

Other types of auditory synesthesia include auditory-tactile synesthesia, in which the experience of hearing sounds causes physical sensations in parts of the body. For example, listening to electronic dance music could cause one to experience a ‘pins and needles’ feeling in the arms. Lexical-gustatory, or sound-gustatory synesthesia, embodies the synesthetic phenomenon where thinking, hearing, or reading sounds and/or words evokes a highly specific smell or taste in the mouth. This is a very rare type of synesthesia (Shapiro, 2022).

Neurophysiological Hypotheses on the Synesthetic Phenomenon

Ongoing research has yet to pinpoint the definitive cause(s) of synesthesia. Present research posits two prevailing neurophysiological hypotheses explaining the cause(s) of the synesthetic condition: the hyperconnectivity theory and the disinhibited feedback theory. The hyperconnectivity theory posits a structural difference in neurophysiology, while the disinhibited feedback theory posits a functional difference in neurophysiology (Grossenbacher & Lovelace, 2001; Ramachandran & Hubbard, 2001; Ward, 2013). The structural approach assumes an actual neurophysiological difference in the neural connectivity amongst synesthetes. The functional approach suggests normal neurophysiology amongst both synesthetes and non-synesthetes - the synesthete’s neurophysiology simply functions differently with the same set of neural connections (Grossenbacher & Lovelace, 2001). There also exists an environmentally-acquired hypothesis by M.R. Watson et al. that ascribes the occurrence of synesthesia to learned, linguistically-influenced conditions that support the development of synesthetic associations (Watson et al., 2017).

The Hyperconnectivity Theory

The hyperconnectivity theory was developed by American neuroscientists V.S. Ramachandran and E.M. Hubbard in 2001. The hyperconnectivity theory hypothesizes that the multimodal neural connections associated with synesthesia are due to defective neural pruning caused by a genetic mutation, resulting in increased structural connectivity of cortical connections (Ramachandran & Hubbard, 2001; Ward, 2013). These genetic mutations may present themselves differently, which may explain the existence of different synesthetic forms (Ramachandran & Hubbard, 2001).

Neural pruning is a natural neurological process which prominently occurs during infancy and between the ages of seven to nine years old due to environmental, genetic, and experiential factors. A 1995 study performed by the neuroscientist Helen Neville showed that verbal speech activated brain waves in both the auditory and visual brain regions of six-month-old infants, but for three-year-old children, speech only provoked auditory regions of the brain. Neville concluded that neural networks of infants were naturally hyperconnected, but were pruned over time by natural genetic and environmental factors. For synesthetes, it is hypothesized that these neural connections are somehow strengthened, rather than pruned (Ravidran, 2015). English synesthetic researchers Simon Baron-Cohen and John Harrison also came to a similar hypothesis that we all might have the capacity for synesthesia until the hyperconnected cortical connections are naturally pruned at approximately three months of age (Sacks, 2008).

The high-level nature of inducing stimuli in cross-modal activation is thought to occur in the cerebral cortex. Cortical areas are connected through hierarchical and reciprocal relationships: one higher area sends driving, feedforward information to another cortical area, then the latter area sends modulating, feedback information back to the higher area (Bagary & Mitchell, 2008). In synesthetes with colored concurrents, this cross-modal activation occurs specifically in the V4 region of the parietal cortex, which is responsible for visual-color processing. An fMRI study of synesthetes showed that the V4 region was activated upon the presence of spoken and visual graphemes, suggesting a form of cross-activation within the hierarchical cortical areas (Bagary & Mitchell, 2008).

Other studies found activation in the lower and higher areas of the parietal areas of the cortex, which is responsible for sensory perception and integration (Bagary & Mitchell, 2008). Diffusion tensor imaging (DTI) also found greater white matter activity and differences in gray matter in the temporal, parietal, and frontal regions of synesthetes, indicating instances of greater structural connectivity (Bagary & Mitchell, 2008; Ward, 2013). These results suggest that synesthesia may be caused by mutation in the genes that control cortical connectivity during development (Bagary & Mitchell, 2008). The mutated genes may cause a difference in the degree of pruning and variations in axon guidance for synaptic connections, resulting in greater connected cortical activity that enters into the conscious experience and presents itself as the synesthetic experience (Hubbard & Ramachandran, 2005; Ward, 2013).

Developmental synesthesia is hereditary, but synesthetic associations and specific types of synesthesia are not hereditary and vary amongst individuals in the same family (Ward, 2013). Since graphemes, phonemes, colors, and music are processed by different areas of the brain, these forms of synesthesia are thought to occur due to different neurological architecture driving the multimodal experience. The fact that individuals in the same family can inherit different forms of synesthesia suggests a common neurophysiological mechanistic cause which may be altered by similar hereditary genetic mutations, resulting in differentiations of neural architecture

(Hubbard & Ramachandran, 2005). Current evidence suggests the involvement of multiple genes in synesthetic inheritance patterns, as well as genetic differences between synesthetic and non-synesthetic family members (Ward, 2013).

The Disinhibited Feedback Theory

The disinhibited feedback theory proposed by P.T. Grossenbacher, a cognitive neuroscientist, and C.T. Lovelace, a neuropsychologist, suggests that synesthesia results from an inhibition failure between adjacent cortical regions that are typically isolated from one another. This inhibition failure causes concurrent sensory pathways to sympathetically activate alongside the inducer pathways, resulting in the synesthetic percept (Grossenbacher & Lovelace, 2001). The disinhibited feedback theory is the result of a functional difference in brain connectivity, meaning that both synesthetes and non-synesthetes have common connective pathways, but these pathways are active in synesthetes and dormant in non-synesthetes (Ward, 2013). Similar to the hyperconnectivity theory, the breakdown in border formation between different cortical regions may be the result of genetic anomalies that can cause different patterns of brain connectivity (Ward, 2013).

In the disinhibited feedback theory, each inducer the synesthete is sensitive to always produces a concurrent experience. The brain has a sensory hierarchy consisting of simple representations that feed forward to higher cortical levels that support more complex representations. Within the sensory pathway, bottom-up signals are accompanied by top-down signals via feedback connections in the hierarchy of converging cortical pathways (Grossenbacher & Lovelace, 2001). In synesthesia, feedback from the higher cortical areas allows the disinhibited inducer pathways to horizontally trigger the concurrent representation pathway, resulting in a different cortical area being activated by input from the ‘incorrect’ sense (“Synesthesia,” 2010).

Evidence supporting functional synesthesia lies in the suggested existence of cross-modal connections present in all humans; certain multi-sensory associations are similar amongst both synesthetes and non-synesthetes. For example, both synesthetes and non-synesthetes associate higher auditory pitches with brighter colors, while lower pitches appear darker in hue. In rare instances, hallucinogenic drugs such as lysergic acid diethylamide (LSD) or psilocybin, the psychoactive substance in magic mushrooms, can induce temporary synesthetic states (Ward, 2013). Studies performed with the kiki/bouba effect, a test that maps similarities in speech sounds and visually-presented shapes, showed that 95% of participants associate the spiky, pointy shape as being named ‘kiki’ and the rounder, blob shape as ‘bouba.’ These results show that the phonetic pronunciations of ‘kiki’ and ‘bouba’ mimic the shapes’ respective contour, showing that auditory language and visual metaphor involve the cross-activation of conceptual mapping between different brain functions, similar to synesthetes’ cross-activation of sensory input (Ramachandran & Hubbard, 2001).

The Environmentally-Acquired Theory

The largely neurophysiological and genetic research focus regarding the existence of synesthesia does not consider the possible environmental influences that may give rise to the synesthetic condition. Contrary to the hyperconnectivity theory and the disinhibited feedback theory, the environmentally-acquired theory posits that synesthesia partly develops through the utilization of learned concurrents to master difficult concepts, such as language acquisition, as a child (Watson et al., 2017). After repeated exposure, the challenging concepts become inducers and automatically trigger concurrent associations that were utilized to master said challenging concepts.

Recent studies have shown that while genetic inheritance plays an important role in synesthetic development, the learning process may contribute an equal, if not more potent influence. Present data reveals that no single synesthetic gene has been discovered, and genetic studies have implicated different genetic causes (Watson et al., 2017).

One hypothesis states that synesthesia develops in part because concurrents are helpful in gaining mastery over difficult learning inducers. The average child begins learning the names of colors from ages four to seven, and begins learning how to read around age six and continues past age eleven. Researchers hypothesize that some children begin utilizing their newfound knowledge of color to master complex linguistic concepts, such as letters, numbers, and words. When a child solves a particular learning challenge with an unusual method, they will continue to employ said method to conquer other difficult concepts, such as units of time or music, resulting in synesthetic relationships with these inducers (Watson et al., 2017).

The Watson et al. study found higher incidences of synesthesia among monolingual speakers of opaque (more grammatically difficult) languages than transparent (more grammatically simple) languages (Watson et al., 2017). For example, a case study found that a woman with grapheme-color synesthesia developed her color association with the Cyrllic language from a set of colored English alphabet refrigerator magnets, which she then transferred over to Cyrillic based on the alphabet’s similarity to English pronunciations (Witthoft & Winawer, 2006).

Another hypothesis states that many inducers are culturally-defined categorical structures learned with some difficulty, such as letters, numbers, and music, suggesting that synesthesia rarely begins with internalized inducers and largely originates from environmental factors (Watson et al., 2017). This effect has been found for those with different types of synesthesia.

Notable Composers/Musicians with Synesthesia

The synesthetic experience has served and inspired musicians of all creeds and creative fields, many of whom rely on their synesthesia to engage in the artistic process. As chromesthesia is the most common and well-documented form of auditory synesthesia, this paper will focus on two musicians with chromesthesia: the twentieth-century modernist composer Olivier Messiaen, and the pop singer-songwriter Lorde.

Olivier Messiaen

Olivier Messiaen (Dec. 10, 1908-April 27, 1992) was a French composer known for his distinct musical identity and rich, complex harmonic language, tonal color, and rhythmic styles inspired by Greek, Indian, and East Asian rhythmic patterns (Ball, n.d.). Messiaen had chromesthesia and experienced musical notes, chords, and his famous Limited Modes of Transposition as a single color or mixture of multiple colors. Messiaen's concurrents for individual musical notes and chords appeared to him in three basic color patterns: single, monochromatic colors; mixed, duo-chromatic colors that blurred into one another, and increasingly complex trichromatic combinations produced by successive chords (Bernard, 1986). Messiaen's chromesthetic experience also included lined parallel colors, and colors flecked, banded, or 'hemmed' within the dominant color. Messiaen regularly documented his colored perception of individual chords in the notes of his musical scores or within the score itself as musical expressions (Bernard, 1986).

One of Olivier Messiaen's most prominent compositions, *Quartet for the End of Time* (1942) (Fr., *Quatuor pour la fin du temps*), depicts one of Messiaen's earliest inclusions of color in his musical scores. At the start of World War II in 1939, Messiaen was drafted into the French army and served as an active-duty hospital nurse ("Five Things," 2021). In May 1940, Messiaen was captured by German Nazi troops and imprisoned in the prisoner-of-war camp Stalag-8A in the German-occupied Polish city of Gorlitz (Rothwell, n.d.). German troops considered Messiaen to be harmless, allowing him to keep his musical scores and providing him with pencils, erasers, and score paper ("Five Things," 2021). Imprisoned in Stalag 8A, Messiaen began to compose *Quartet for the End of Time* during the winter of 1940-1941, drawing inspiration from the New Testament's Book of Revelations' description of the end of time as the end of past, present, and future in an achievement of eternity (Rothwell, n.d.). The piece was dually inspired by his witnessing of the Northern Lights, which Messiaen believed to be hallucinations induced by hunger and freezing winter temperatures ("Five Things," 2021).

Messiaen composed *Quartet for the End of Time* based on the available instruments and other imprisoned instrumentalists in Stalag-8A. The resulting instrumentation includes a violin, a cello, a B-flat clarinet, and a piano, which was played by Messiaen when premiering the piece in Stalag-8A (Rothwell, n.d.). It is in the description of *Quartet for the End of Time's* second of eight segments where Messiaen's first instance of colored musical expression appears, reading, "Vocalise, for the angel who announces the end of Time…From the piano, soft cascades of blue-orange chords, encircling with their distant carillon the plainchant-like recitativo of the violin and cello" (Rothwell, n.d.; Messiaen, 1957).

Lorde

Ella Yelich O'Connor (b. 1996), known by her stage name Lorde, is a New Zealand-based pop singer/songwriter lauded for her introspective lyricism and rhythmic creativity (Weiner, 2017; Lanksy, n.d.). Lorde rose to sudden critical acclaim at the age of sixteen with her first single, "Royals" in 2012, which earned her two Grammys, including 'Song of the Year.' Her debut album, *Pure Heroine* (2013), sold over three million copies internationally and was applauded for brooding and sophisticated lyricism and thematic motifs (Lanksy, n.d.).

Lorde has chromesthesia and describes her music-making in colorful terms, specifically curating her music to the "far off and foggy" percepts she experiences when engaged in the beginning stages of composition. Lorde's goal is to make the configuration of chords, rhythms, textures, and emotions accurately depict the colors and contours she 'sees' (Weiner, 2017). For example, in a 2015 Q&A Tumblr session, Lorde stated that the song "Tennis Court" originally sounded "too tan" and did not match the green color she envisioned for the song - she then achieved the desired green by altering the pre-chorus (Geggel, 2017).

While composing her sophomore album *Melodrama* (2017), Lorde color-coded notes she wrote for each song and pasted the notes on a large idea wall, using different hues to denote different musical and lyrical themes. Lorde's wall of notes permitted her to see her synesthetic experience in one place, allowing her to see the color patterns of her lyrical ideas and any color 'imbalances,' which she would then edit and rearrange to achieve the colors she saw. Lorde also experiences her three albums in terms of color: *Pure Heroine* (2013) is green, *Melodrama* (2017) is violet, and *Solar Power* (2021) is gold (Vogue, 2021).

Lorde frequently incorporates her chromesthesic percepts in her live performances. During her 2022 *Solar Power Tour*, Lorde's main stage props were colored stage lighting and a large light-up screen. For every performed song, the stage lighting and screen would change colors to match her personal color association with each song. For example, her melancholic hit song “Ribs” swathed the entire stage in a sky-blue hue, the party song “Perfect Places” danced in a dark blue and magenta mix, and her sunny, day-drinking-at-the-beach song “Solar Power” bathed the stage in a soft yellow glow (*Solar Power Tour*, 2022).

Conclusion

The existence of synesthesia reveals some of the vast intricacies of the human brain that remain largely misunderstood and have the potential to uncover new breakthroughs in neuroscience. Synesthesia’s common occurrence suggests the regularity of neurodivergence and challenges current understanding of sensation and perception, neural connectivity, and the emotional and philosophical influences of neurophysiological phenomena. For synesthetes in the creative field, their synesthesia serves as a guiding force for their art, inspiring the creative process and enhancing their interaction with art. While synesthetic research and debate continues, synesthesia will continue to influence and inspire the lives of synesthetes.

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