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A Discussion on Synesthesia

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Synesthesia is a rare condition in which different sensory modalities pair during the perceptual process. Grapheme-color is the most commonly seen type of synesthesia where a color is perceived when viewing a letter or number. For many years synesthesia was not widely researched due to the rarity of the condition, about 1 in 2000 people in the population are affected, and there not being enough tangible scientific evidence to determine whether synesthesia was real. Once researchers determined synesthesia was a real condition there was a need for tests and criteria to be developed that could be used to determine whether a person had synesthesia versus hallucinations as a byproduct of a different disorder. Current research on synesthesia has been able to show the genetics of the condition along with the many different ways synesthesia can be presented.

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The Diagnostic and Statistical Manual of Mental Disorders (DSM-5, 2013) describes synesthesia as a condition where stimulation of one modality, be it sensory or cognitive, will result in an automatic experience in the other modality. The root word definition for the term synesthesia originates from Ancient Greek, which denotes "syn" as together or with and "aesthesia" as sensation, which gives a literal translation of sensations together (Robertson & Sagiv, 2005). The most common expression of synesthesia comes in the grapheme-color form of the condition which states that specific colors are perceived with certain letters and numbers (Brang, Rouw, Ramachandran & Coulson, 2011). The synesthetic perceptions can also be experienced if the synesthete were to think of and visualize the letter A, the color would then be associated with that letter as well, even though the synesthete is not directly looking at the letter.

Synesthesia has a wide range of sensory modality pairings; such as grapheme-color (i.e., letters and numbers associated with color), colored hearing (i.e., sounds produce visual images, most commonly colors), and colored time units (i.e., months, weeks, days are associated with a color), to name a few of the different sensory pairings (Marks, 1975; Robertson & Sagiv, 2005). Each of the different sensory pairings give rise to a highly individualized synesthetic experience, causing an inability for some aspects of the condition to be generalized. Therefore, only basic information such as, type of synesthesia and its unique sensory pairings can be generalized during the identification process of the condition.

The particularly interesting aspect of synesthesia and what drives research is that two completely distinct, differently processed senses can be paired together during perception. As shown by Robertson and Sagiv (2005), synesthesia is a not a condition

that can be learned, instead it is something that is gained through development, so much so, that people who experience synesthesia say they did not know there was a problem with, or a difference in how they experienced the world with synesthesia (Robertson & Sagiv, 2005). Due to a lack of knowledge, for many years research was not conducted on how the different sensory modalities can be paired, but whether the synesthesia experiences were real, rather than hallucinatory perceptions as side effects of disorders, such as schizophrenia, or substance abuse.

The pairing of the separate senses creates a different neural mapping than is seen when a non-synesthete perceives the same stimuli. The different neural mappings of a synesthete and a non-synesthete can shed light onto the synesthetic perceptual process and in turn the normal perceptual process. Both the synesthetic and normal perceptual process have more to be expounded upon due to the ever-increasing abilities of technology and discoveries that are made through new technology (e.g., the fMRI giving way to knowledge of how stimuli are perceived visually through showing activation in the V4/V8 pathways, Nunn et al., 2002). Due to the widely-individualized perceptions of synesthesia, it is difficult to develop a specific guideline and set of psychological determining tests for synesthesia. For many years synesthesia was ignored by the scientific community and regarded as hallucinations of the people experiencing it. This discussion on synesthesia will provide the current knowledge on synesthesia and how it is diagnosed. The purpose is to document the growth in research and in science as time has passed.

A BRIEF HISTORY OF SYNESTHESIA

The first authentic accounts of synesthesia documented began in the early nineteenth century. That assumption is not to discount any accounts of possible synesthesia referenced before then, but with current evidence, the accounts before the nineteenth century do not hold to be factual (Jewanski, Day & Ward, 2009). The first known case of synesthesia is of Georg Tobias Ludwig Sachs (1812), which is documented in a medical dissertation Sachs wrote documenting his albinism, in which his synesthesia is referenced "abruptly and briefly" (Jewanski, Day & Ward, 2009). The next account of synesthesia does not occur for more than 70 years after Sachs' dissertation, in which Sir Francis Galton describes synesthesia is his book *Inquires into Human Faculty and its Development* (1883).

In the medical dissertation, Sachs (1812) describes "the brother" (himself) as having grapheme-color synesthesia where letters and numbers have colors. Along with the grapheme-color synesthesia, Sachs (1812) describes colored time units and sound-color synesthesia, all of which evoke a colored perceptual experience in "the brother's" mind. In Sachs' dissertation he does not associate his synesthesia with his albinism due to a referenced meeting of a man who experienced similar synesthetic qualities (Sachs, 1812; Jewanski, Day & Ward, 2009).

The next accounts of synesthesia come in the manuscript, *Inquiries into Human Faculty and its Development* (1883). Sir Francis Galton begins one of the chapters with a basic description of grapheme-color synesthesia, in which numbers and letters are viewed as having colors associated with them. Galton (1883) illustrates the synesthetes as not being content with giving a simple description of the color they are seeing, but would rather give a very specific detailed depiction of their synesthetic color. Due to the amount of detail given to Galton, he painstakingly detailed replications of the colors

and their associated letter or number in a set of figures within his book (Galton, 1883). The particularity of the synesthetes with their synesthetic colors is one that has been accounted for many times by researchers (e.g., see Robertson & Sagiv, 2005), which is of worthy notation to indicate that Galton was indeed working with individuals who experienced synesthesia.

After the account of synesthesia from Sir Francis Galton, research on synesthesia increased slightly until the early 1930s and was based, for the most part, on introspection accounts from individuals with synesthesia (Harrison & Barron-Cohen, 1995). Though, there is trouble with the reports of synesthesia from that time frame due to the reasoning that most documentation comes from introspection. Harrison and Barron-Cohen (1995) explain that introspection is an unreliable form of detailing human cognition, in that the subjects only report information that is different from what is regarded to be normal. To be completely accurate in an introspection description the subject would need to report every detail without a bias to shed themselves in a positive light.

Beginning in the 1930s behaviorism theories began to increase in popularity in psychology, due to its concentration on observable behaviors. The tangible display of behaviors, which can be observed and experimented on, dominated psychology for the entirety of the popularity of behaviorism. Therefore, research on synesthesia which relied on introspection and referenced a person's mental state was subsequently disregarded from most research (Harrison & Barron-Cohen, 1995). It wasn't until the 1970s that behaviorism began to lose popularity as some items could not be explained psychologically, such as the acquisition of language (Harrison & Barron-Cohen, 1995). Around that time, at the end of behaviorism, synesthesia began to increase in popularity and research subsequently followed to determine factors such as whether the condition was real and how the process worked.

The most important question researchers were aiming to answer in the early days of research on synesthesia was whether the condition was real and not a side effect of other disorders or substance abuse. To determine the authenticity of the condition, psychologists needed to be able to obtain physical and physiological evidence of the condition (Costa, 1996) rather than documentation of self-report. In a commentary on work by Cytowic, Costa (1996) emphasizes the need for new neuropsychological evidence to fully determine the validity of the condition. The need for new evidence is due to the reasoning that at the time of Cytowic's review the new evidence showing cross modal communication was overlooked. The disregard of the new evidence was concerning for Costa considering it was the cornerstone of validating all accounts of synesthesia.

The criteria for any phenomenon to be accepted in the scientific community are very simple and follow three conditions (Robertson & Sagiv, 2005). The first must be that the phenomenon is real, which is what most of the early research on synesthesia sought out to display (Robertson & Sagiv, 2005). The next condition is that there must be some potential explanations for the development of the condition (Robertson & Sagiv, 2005), which is the reason for the genetic tests on synesthetes. The last condition is the phenomenon must be far-reaching in its associations and not be limited to one specialty (Robertson & Sagiv, 2005). Due to the acceptance of synesthesia as a condition in the scientific community researchers attempted create many different diagnostic tests to separate the true accounts from the fraudulent accounts of synesthesia.

Brain imaging techniques have been very useful in showing the validity of synesthesia and its authenticity by presenting the different brain area activations that are congruent with the experiences

of the synesthetes. Through the different imaging techniques, it can be concluded that synesthesia is a real condition that affects a small portion of the population. The pairing of different sensory modalities which can be described in detail by the synesthete and shown through the brain imaging techniques give a possible explanation for the occurrence of synesthesia.

SYNESTHESIA TESTS

The first test to determine the validity of synesthesia was the test of genuineness, which was developed by Baron-Cohen, Wyke and Binnie (1987). The test of genuineness established validity of synesthesia by showing a consistency over time of the colors described by the subject upon hearing 50 meaningful word, the seven days of the week, 20 Christian names, and the 26 letters of the alphabet (Baron-Cohen, Wyke, & Binnie, 1987). After the initial test, the synesthete was tested again after a ten-week delay, in which the results showed consistency of the synesthetic colors chosen for each item (Baron-Cohen, Wyke, & Binnie, 1987). The test of genuineness created by Baron-Cohen et al. (1987) has been challenged in recent research on its validity by the modality and variability of the synesthetic experience due to the new research testing the consistency of the colors over a longer period such as a lifetime for the synesthetes (Brang et al., 2011).

The test of genuineness (Baron-Cohen et al., 1987) came with some limitations such as a reliance on the verbal description of color given by the synesthete. To decrease the limitations created by the original test of genuineness, researchers sought out to revise the test to produce less limitations and increase the accuracy for color-grapheme synesthesia (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006). The revised test of genuineness included a CD that contained 99 sounds, which were broken down into 51 words and 48 non-word sounds, and Pantone color swatches (Asher et al., 2006). The test was conducted in a room lit solely by artificial light and the subjects were instructed to choose the color swatch that closely related to the synesthetic color experience produced by the word heard, which followed the same categories as in the original test of genuineness (Asher et al., 2006). The synesthetes were retested with the same criteria for the revised test of genuineness after a minimum of one month to determine the consistency and validity of the synesthesia experienced by the subjects. The results from the revised test of genuineness were much like the results produced from the original test of genuineness. Due to the new criteria for testing, the results were more reliable since the colors were much more standardized.

Since the test of genuineness and the revised version do not offer quantifiable data for comparison, along with the fact there is no standardized scoring system or phrasing of questions, researchers have sought out to remedy this limitation of synesthesia research (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). Eagleman et al., (2007) developed the synesthesia battery which is comprised of a questionnaire (to determine type of synesthesia experienced) and software programs that offer immediate results for synesthetes and researchers. The synesthesia battery uses a standard scoring system to quantify results for the ease of data analysis and comparison (Eagleman et al., 2007). The other tests included in the battery are a grapheme-color consistency test, a speeded congruency test to detract cheating in the previous test, grapheme contrast to separate lower from higher synesthetes, and many other tests that are specific for the many other different types of synesthesia (Eagleman et al., 2007).

TYPES OF SYNESTHESIA

The process of synesthesia is one of automation (Ward & Mattingley, 2006) therefore it is easy to fall under the assumption that all synesthesia occurs through development. Although, that is not the case, some instances of synesthesia can be developed later in life either through substance abuse, brain injury, or a brain tumor. The three ways in which synesthesia can appear are developmental synesthesia (i.e., synesthetic perceptions that begin early in life), acquired synesthesia (i.e., synesthesia as the result of brain injury or brain tumor), and pharmacological synesthesia (i.e., synesthesia as the result of hallucinogenic substances) (Grossenbacher & Lovelace, 2001). The most researched of the three is the developmental type of synesthesia, which contains most of the different sensory modality pairings. The acquired and pharmacological synesthesia are less consistent and much less automatic; therefore, they are more difficult to research and have less subjects for research due to the methods in which the synesthesia occurs.

Sinke et al. (2012) describes pharmacological or drug induced synesthesia as a condition that is experienced temporarily under the effects of a hallucinogenic drug such as LSD. During the intoxication period, a dream-like state of consciousness occurs in which the hallucinations are manifested in the form of geometric patterns (Sinke et al., 2012). The synesthetic experience produced by the hallucinogenic drugs is a more abstract type of synesthesia and requires the state of mind drugs produce to be achieved; whereas developmental synesthesia is automatic and simple in the synesthetic perceptions. Due to the process in which the synesthetic experience is created, taking hallucinogenic drugs, research on the subject has not been performed often, or at all, in recent years. The reasoning behind the lack of research is made under the assumption that instructing participants to take hallucinogenic drugs for experimentation and observation would be considered unethical to the IRB (Institutional Review Board).

Another variety of synesthesia is the acquired type, where some type of brain injury or tumor has occurred within the sensory areas. The acquired type synesthete is not able to see a full range of colors as a developmental synesthete would, but rather they perceive colored flashes (Sinke et al., 2012). Consequently, acquired synesthesia is not as consistent as developmental synesthesia is, rather once a synesthetic perception pairing has occurred relative stability in the synesthesia is reached (Sinke et al., 2012). Although, current research has shown that the same stimulus may evoke a different synesthetic perception when viewed on different occasions due to the instability created by the brain injury (Sinke et al., 2012). Along with the instability of the sensory pairings the synesthesia event is not automated completely, as in developmental synesthesia, rather the perceptual events happen some of the time (Sinke et al., 2012).

As previously, stated most occurrences of synesthesia appear through the developmental process where, for example, the synesthete will have always made the color-grapheme or sound-color associations and will not know a life without them (Robertson & Sagiv, 2005). The most frequently occurring type of synesthesia as shown by the synesthesia list (created by Sean Day; Day, 1992) is the color grapheme type, in which a color is synesthetically perceived when a letter or number (grapheme) is viewed by the subject (Brang et al., 2011; Day, 1992). Another interesting feature of synesthesia is that the synesthete's attention can be switched between the printed and synesthetic color (Robertson & Sagiv, 2005). The ability for the

synesthete to switch between the two different perceptions is a particularly noteworthy feature of synesthesia since it is not a condition that can be fully or easily repressed as shown by Ward and Mattingley (2006).

Since the association of the color and grapheme are a determining factor for true synesthesia, it is an important finding that the subjects hold the same color and grapheme associations throughout a lifetime (Ward & Mattingley, 2006), which was shown by Baron-Cohen et al. (1987). The researchers revealed the color experienced by the synesthete typically does not change upon retesting of the association for that specific grapheme, through the test of genuineness (Baron-Cohen et al., 1987). The test of genuineness was created by Baron-Cohen et al. (1987) to be used to test the associations made by the synesthetes for consistency.

The way synesthesia can be perceived adds another factor into the idiosyncrasies of the condition. Currently, there are three different styles that are similar in their qualities. The first and most researched is associative vs. projector, which is the process where the stimulus will create a concurrent perception in either the "mind's eye" (i.e., associative) or on the stimulus (i.e., projector) (Brang et al., 2011). The second way synesthesia is perceived is much like associative synesthesia, which is synesthetic conception, where the thought of a certain concept can induce the concurrent (synesthetic experience) (Grossenbacher & Lovelace, 2001). The converse of conception synesthesia is like projector synesthesia, and is called synesthetic perception which is when the concurrent or color is induced by the sensory stimuli (Grossenbacher & Lovelace, 2001).

The last way synesthesia can be perceived is intermodal vs. intramodal synesthesia. Intermodal (cross-modal) synesthesia is when the stimulus or inducer is in a different sensory modality than the synesthetic perception or concurrent (Robertson & Sagiv, 2005). An example of intermodal synesthesia is color-hearing in which a sound stimulus induces a visual color concurrent. Intramodal (cross-dimensional) synesthesia by comparison is different in that the inducer and concurrent are within the same modality, but differ in dimension (Robertson & Sagiv, 2005). An example of intramodal synesthesia would be the most frequent type of synesthesia seen, which is the color-grapheme type in which a visual grapheme stimulus induces a visual color concurrent.

GENETIC PREVALENCE OF SYNESTHESIA

To determine the genetic prevalence of synesthesia Baron-Cohen, Burt, Smith-Laittan, Harrison and Bolton (1996) conducted three separate studies. The first two studies were advertisements placed in two separate magazines, the former to reach the general public and the latter to reach students at the university (Baron-Cohen et al., 1996). The advertisements requested individuals who experienced synesthesia to contact the researchers; upon their responses two researchers from the group tested them for the genuineness of their synesthesia (Baron-Cohen et al., 1996).

The genetic prevalence finding from studies one and two found that for every six females that had synesthesia, one male also had synesthesia, giving a 6-female: 1-male ratio (Baron-Cohen et al., 1996). The higher female to male ratio indicated there was a genetic underlying in the development of synesthesia, which agreed with Rich, Bradshaw, and Mattingley's 2005 findings. The same findings of a genetic prevalence over a longer period and from separate research groups give a strong indication that neither study discovered a fluke in the condition, but rather a genetic approach that needed further study.

The third study by Baron-Cohen et al. (1996) aimed to test the genetic prevalence of synesthesia by looking to familial aggregation, which is the grouping of certain traits, behaviors, or disorders. To determine the familial aggregation, Baron-Cohen et al. (1996) studied six families selected from the International Synesthesia Association's cases who had established cases of synesthesia within the families. To establish the authenticity of synesthesia within the families, the researchers used the test of genuineness on the synesthetes and their first-degree relatives. The researchers found all families were a multiplex for synesthesia (Baron-Cohen et al, 1996).

From the results, Baron-Cohen et al. (1996) hypothesized three genetic explanations for synesthesia. These explanations were autosomal recessive (i.e., both parents must pass on at least one gene for synesthesia for the child to develop the condition), autosomal dominant with sex limitation (i.e., one parent passes the synesthesia gene to the child, mother to daughter, father to son), and sex-linked dominance with lethality (i.e., the synesthesia gene is X-linked and passed from mother to daughter, with a lethality from mother to son). The researchers determined at the time the most viable genetic explanation for synesthesia is the sex-linked dominance with lethality because it provides a reason for a female prevalence of synesthesia (i.e., 6: 1 female to male ratio; Baron-Cohen et al., 1996). Although, more genetic pedigrees would be required to explain the expression of males with synesthesia due to the evidence of the synesthesia gene being linked with a lethality gene.

Even though synesthesia appears to be genetically linked, there is no explanation as to how there are so many different types of synesthesia (Brang & Ramachandran, 2011). For example, in families that express synesthesia, each member could have a different type of synesthesia (i.e., color-grapheme or sound-color), which gives the implication that the genetics give way to predisposition for the condition and not how it can be expressed (Brang & Ramachandran, 2011). Further research into the prevalence sampling studies also indicate there is less of a gender gap, which indicates there may have been flaws in the designs of the previous studies that gave a gender gap in the prevalence of synesthesia (Brang & Ramachandran, 2011).

CURRENT RESEARCH AND FUTURE CONSIDERATIONS

Researchers have made much progress in the standardization of testing for synesthesia, but it's possible that a new test should be developed that can be easily used on the entire population (i.e., increase generalizability). The standardization of a synesthesia test would be beneficial for researchers to determine the true number of how much of the population synesthesia affects, since much of the current research indicate different numbers for the affected population.

Another discrepancy within the current research are the genetic implications of the transmission of synesthesia. The discrepancies within the genetics could be largely due to the high variability within the expression of synesthesia. Although, that does not seem plausible, in all the research, the researchers controlled for the variability in using the same type of synesthetes in the genetic comparisons. Therefore, it would be beneficial in the genetic research to determine why there are differences in the linkages on chromosomes. While the genetic linkage tests have shown there is some type of genetic linkage and familial linkage for synesthesia, there is not a clear explanation for the transmission. Upon further research, the genetic linkage of synesthesia should be further determined to give a

better indication as to how synesthesia is transferred from parent to child, along with how it is developed.

REFERENCES

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders: DSM-5*. Washington, D.C: American Psychiatric Association.

Asher, J. E., Aitken, M. R. F., Farooqi, N., Kurmani, S., & Baron-Cohen, S. (2006). Diagnosing and phenotyping visual synesthesia: a preliminary evaluation of the revised test of genuineness (TOG-R). *Cortex, 42* (2006), 137-146.

Asher, J. E., Lamb, J. A., Brocklebank, D., Cazier, J. B., Maestrini, E., Addis, L., Sen, M., Baron-Cohen, S., & Monaco, A. P. (2009). A Whole-Gemone Scan and Fine-Mapping Linkage Study of Auditory-Visual Synesthesia Reveals Evidence of Linkage to Chromosome 2q24, 5q33, 6p12, and 12p12. *AJHG, 84* (2), 279-285.

Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., & Bolton, P. (1996). Synesthesia: Prevalence and familiality. *Perception, 25*, 1073-1079.

Baron-Cohen, S. Harrison, J. Goldstein, L. H., & Wyke, M. (1993). Coloured speech perception: Is synaesthesia what happens when modularity breaks down? *Perception, 22*, 419–426.

Baron-Cohen, S., Wyke, M. A., & Binnie, C. (1987). Hearing words and seeing colours: An experimental investigation of a case of synaesthesia. *Perception, 16*, 761-767.

Brang, D., & Ramachandran, V. S. (2011). Survival of the Synesthesia Gene: Why Do People Hear colors and Taste Words? *PLoS Biology, 9*, 1-6.

Brang, D., Rouw, R., Ramachandran, V. S., & Coulson, S. (2011). Similarly Shaped Letters Evoke Similar Colors In Grapheme–Color Synesthesia. *Neuropsychologia, 49*, 1355–1358.

Costa, L. (1996). Synesthesia - A Real Phenomenon? Or Real Phenomena? *Psyche, 2*(10), 2(26).

Day, S. (1992). Synesthesia List. Retrieved from http://www.daysyn.com/Synesthesia-List.html

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.

Galton, F. (1883). *Inquiries into Human Faculty and its Development*. Dent and Sons, London.

Gregersen, P. K., Kowalsky, E., Lee, A., Baron-Cohen, S., Fisher, S.E., Asher, J. E., Ballard, D., Freudenberg, J., & Li, W. (2013). Absolute pitch exhibits phenotypic and genetic overlap with synesthesia. *Human Molecular Genetics, 22* (10), 2097-2104.

Grossenbacher, P., & Lovelace, C. (2001). Mechanisms of Synesthesia: Cognitive and Physiological Constraints. *Trends in Cognitive Sciences, 5* (1), 36-41.

Harrison, J., & Baron-Cohen, S. (1995). Synesthesia Reconciling the Subjective with the Objective. *Endeavour, 19*, 157–160.

Jewanski, J., Day, S., & Ward, J. (2009) A Colorful Albino: The First Documented Case of Synaesthesia, by Georg Tobias Ludwig Sachs in 1812. *Journal of the History of the Neurosciences, 18* (3), 293-303

Jordan, D. S. (1917). The colors of letters. *Science, 46*, 311–312.

Leeuwen, T. M., Den Ouden, H. E. M., & Hagoort, P. (2011). Effective Connectivity Determines the Nature of Subjective Experience in Grapheme-Color Synesthesia. *The Journal of Neuroscience, 31* (27), 9879-9884.

Marks, L. (1975). On Colored-Hearing Synesthesia: Cross-Modal Translations of Sensory Dimensions. *Psychological Bulletin, 82* (3), 303-331.

Niccolai, V., Jennes, J., & Stoerig, P. (2012). Modality and Variability of Synesthetic Experience. *American Journal of Psychology, 125* (1), 81-94.

Nunn, J. A., Gregory, L. J., Brammer, M., Williams, S. C. R., Parslow, D. M., Morgan, M. J., Morris, R.G., Bullmore, E. T., Baron-Cohen, S., & Gray, J. A. (2002). Functional magnetic resonance imaging of synesthesia: activation of V4/V8 by spoken words. *Nature Neuroscience, 5*(4), 371-375.

Rich, A. N., Bradshaw, J. L., & Mattingley, J. B. (2005). A systematic, large-scale study of synaesthesia: implications for the role of early experience in lexical-colour associations. *Cognition, 98*, 53-84.

Robertson, L. C., & Sagiv, N. (Eds.). (2005). *Synesthesia: Perspectives from Cognitive Neuroscience*. New York, NY: Oxford University Press.

Rogowska, A. (2011). Categorization of Synesthesia. *Review of General Psychology, 15* (3), 213-227.

Sachs, G. T. L. (1812). *Histoia naturalis Duorum Leucaethopium Auctoris Ipsius et Sororis eius.* Thesis presented at the Friedrich-Alexander University, Erlangen, Germany.

Safran, A. B., & Sanda, N. (2015). Color Synesthesia. Insight into Perception, Emotion, and Consciousness. *Current Opinion in Neurology, 1*, 36-44.

Simner, J., Ward, J., Lanz, M., Jansari, A., Noonan, K., Glover, L., et al. (2005). Non-random associations of graphemes to colours in synaesthetic and non-synaesthetic populations. *Cognitive Neuropsychology, 22* (8), 1069-1085.

Sinke, C., Halpern, J. H., Zelder, M., Neufeld, J., Emrich, H. M., & Passie, T. (2012). Genuine and drug-induced synesthesia: a comparison. *Consciousness and Cognition, 21* (2012), 1419-1434.

Smilek, D., Moffatt, B. A., Pasternak, J., White, B. N., Dixon, M. J., & Merikle, P. M. (2001). Synesthesia: A case study of discordant monozygotic twins. *Neurocase, 8* (2001), 338-342.

Tomson, S. N., Avidan, N., Lee, K., Sarma, A. K., Tushe, R., Milewicz, D. M., Bray, M., Leal, S. M., & Eagleman, D. M. (2011). The genetics of colored sequence synesthesia: Suggetive evidence of linkage to 16q and genetic heterogeneity for the condition. *Behavioral Brain Research, 223* (1), 48-52.

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* (2006), 264-280.

Ward, J., & Mattingley, J. B. (2006). Synaesthesia: An Overview of Contemporary Findings and Controversies. *Cortex, 42* (2006), 129-136.

Weiner, J. (2017). The Return of Lorde. *New York Times*. Retrieved from https://www.nytimes.com/2017/04/12/magazine/the-return-of-lorde.html?_r=0