Synesthesia

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Glossary

Concurrent The concurrent refers to the synesthetic experience which can involve color, texture, a spatial location or a feeling. Concurrents are typically percept-like, however, a synaesthete can easily distinguish synesthetic and veridical experience.

Congenital synesthesia A non-pathological variation of experience that affects a small proportion of the general population, emerges early in life, is triggered automatically, and results in the conscious experience of a stimulus property that is not physically present such as a color experience when looking at a black letter or number.

Hyper-connectivity The brains of synesthetes show stronger connectivity between areas involved in processing the synesthetic inducers and concurrents (i.e., cross-activation). They also show stronger connectivity as a whole.

Inducer The inducer is a stimulus that elicits the synesthetic experience such as a grapheme, a word, or a sound. Inducers are typically concepts, that is, even the idea can induce a synesthetic experience.

What is Synesthesia?

The term "synésthesie", adopted from the Greek noun "συναισθησία" has been introduced by Vulpian in the 19th century. Synesthesia is used as an umbrella term to refer to a mixing of the senses in various contexts. In literature, synesthesia is used for metaphorical language (for example, "a sharp cheese", "to see red", etc.). More generally, it can also refer to cross-modal correspondences such as associating small objects with high pitch and light colors, and large objects with low pitch and dark colors. Synesthesia can also refer to experiences in transient altered states of consciousness in which visual and auditory hallucinations co-occur, for example after the intake of psychedelic drugs such as LSD or Mescal (Luke and Terhune, 2013). Moreover, some kind of synesthesia can emerge as a result of brain lesions or sensory loss (Armel and Ramachandran, 1999; Ro et al., 2007). However, here the focus is on the congenital, developmental form of synesthesia that emerges early in life, is triggered automatically and results in the conscious experience of a stimulus property that is not physically present such as a color experience when looking at a black letter or number.

Developmental or congenital synesthesia is an individual difference property, a variation of experience that affects a small proportion, about 2%–4%, of the general population (Simner et al., 2006b; Carmichael et al., 2015, 2019). It involves the conscious and automatic co-activation of a concurrent sensation in response to an inducing stimulus. There are many different types of synesthesia, and typically the type of synesthesia is named according to the inducer-concurrent pairing, that is, grapheme-color synesthesia when a color experience is triggered by a letter printed in black (Grossenbacher and Lovelace, 2001). The binding between the stimulus that induces the sensation and the concurrent sensation emerges early in development and typically remains

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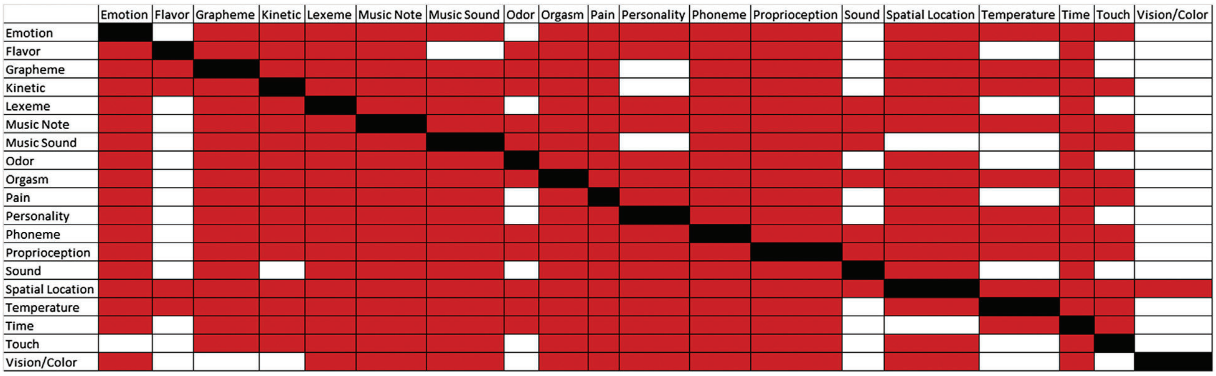

	Emotion	Flavor	Grapheme	Kinetic	Lexeme	Music Note	Music Sound	Odor	Orgasm	Pain	Personality	Phoneme	Proprioception	Sound	Spatial Location	Temperature	Time	Touch	Vision/Color
Emotion	⬛	⬜	🟥	🟥	🟥	🟥	🟥	⬜	🟥	🟥	🟥	🟥	🟥	⬜	🟥	🟥	🟥	🟥	⬜
Flavor	🟥	⬛	🟥	🟥	🟥	🟥	⬜	🟥	🟥	🟥	🟥	🟥	🟥	⬜	🟥	⬜	🟥	⬜	⬜
Grapheme	🟥	🟥	⬛	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬜	🟥	🟥	⬜	🟥	🟥	🟥	⬜	⬜
Kinetic	🟥	🟥	🟥	⬛	🟥	🟥	🟥	🟥	🟥	🟥	⬜	🟥	🟥	⬜	🟥	🟥	🟥	🟥	⬜
Lexeme	🟥	⬜	🟥	🟥	⬛	🟥	🟥	⬜	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬜	🟥	⬜	⬜
Music Note	🟥	⬜	🟥	🟥	🟥	⬛	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬜
Music Sound	🟥	⬜	🟥	🟥	🟥	🟥	⬛	🟥	🟥	🟥	⬜	🟥	🟥	🟥	⬜	⬜	🟥	🟥	⬜
Odor	🟥	⬜	🟥	🟥	🟥	🟥	🟥	⬛	🟥	🟥	🟥	🟥	🟥	⬜	🟥	⬜	🟥	⬜	⬜
Orgasm	🟥	⬜	🟥	🟥	🟥	🟥	🟥	🟥	⬛	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬜
Pain	🟥	⬜	🟥	🟥	🟥	🟥	🟥	⬜	🟥	⬛	🟥	🟥	🟥	⬜	🟥	⬜	🟥	🟥	⬜
Personality	🟥	⬜	🟥	🟥	🟥	🟥	🟥	⬜	🟥	🟥	⬛	🟥	🟥	⬜	🟥	🟥	🟥	⬜	⬜
Phoneme	🟥	⬜	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬛	🟥	🟥	🟥	🟥	🟥	🟥	⬜
Proprioception	🟥	⬜	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬛	🟥	🟥	🟥	🟥	🟥	⬜
Sound	🟥	⬜	🟥	⬜	🟥	🟥	🟥	⬜	🟥	🟥	🟥	🟥	🟥	⬛	🟥	⬜	🟥	⬜	⬜
Spatial Location	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬛	🟥	🟥	🟥	🟥
Temperature	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬜	🟥	⬛	🟥	🟥	⬜
Time	🟥	⬜	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	⬜	⬜	🟥	⬛	🟥	⬜
Touch	⬜	⬜	🟥	🟥	🟥	🟥	🟥	⬜	🟥	🟥	🟥	🟥	🟥	⬜	🟥	⬜	🟥	⬛	⬜
Vision/Color	🟥	⬜	⬜	⬜	🟥	🟥	🟥	⬜	🟥	🟥	🟥	🟥	🟥	⬜	🟥	⬜	🟥	⬜	⬛

Fig. 1 Seventy-three types of synesthesia according to http://www.daysyn.com/Types-of-Syn.html. The left hand column refers to inducers; the top row refers to concurrents. *White* indicates the types that have been documented; *red* indicates no case of this type has yet been recorded.

constant throughout the lifespan, although a decline in number and intensity may occur across the adult lifespan (Meier et al., 2014). The conscious experience is uni-directional, that is, the inducer elicits a conscious concurrent sensation, but the concurrent does not trigger the conscious experience of the inducer. Nevertheless, on the level of the semantic representation, the association between inducer and concurrent can affect behavior bi-directionally (Kadosh et al., 2005; Meier and Rothen, 2007).

The most frequent forms of synesthesia involve sequences such as letters, numbers, and tones as inducers and spatial forms, textures, and colors as concurrents (Simner et al., 2006b; Rich et al., 2005; Novich et al., 2011; Sagiv et al., 2006). Other types of synesthesia include lexical-gustatory synesthesia (Simner and Ward, 2006), for which words elicit olfactory sensations, or "hearing motion" in which type synesthetes hear sounds when they see images flash or move, even when no physical sound is present (Saenz and Koch, 2008). At present, at least 73 different types have been documented (see **Fig. 1**). Often one person will experience several types of synesthesia (i.e., multiple synesthesia).

The particular associations (i.e., inducer-concurrent pairs such as grapheme-color) are typically idiosyncratic at the individual level and stable across time. However, across a large number of synesthetes, the frequency of grapheme-color pairings has a striking resemblance to the grapheme-color pairings that emerge in a non-synesthete sample when asked to match graphemes to colors (Simner et al., 2006a).

The consistency of the synesthetic associations is a defining characteristic of synesthesia and is considered as the gold standard to characterize synesthetes in scientific studies (Asher et al., 2006; Baron-Cohen et al., 1987; Rich et al., 2005; Simner et al., 2006b; Cytowic and Eagleman, 2002). So far, most research has been conducted on grapheme-color synesthesia, most likely due to the relatively high prevalence and due to the availability of simple consistency measures and clear definitional criteria. Consistency is typically assessed by asking synesthetes to report their specific inducer concurrent mappings repeatedly, often with a long time interval between measurements. For grapheme-color synesthetes, color pickers are used which can vary according to the graduation of the colors (see **Fig. 2**).

Another core criterion of synesthesia, its automaticity, is usually tested with a variant of the Stroop test. For grapheme-color synesthesia, the synesthetic Stroop test involves the presentation of colored graphemes that are either congruent or incongruent to the grapheme-color association of a particular synesthete and the participant is required to name the color of the grapheme as quickly as possible. This test has often been used to demonstrate the genuineness of synesthesia, because synesthetes show slower

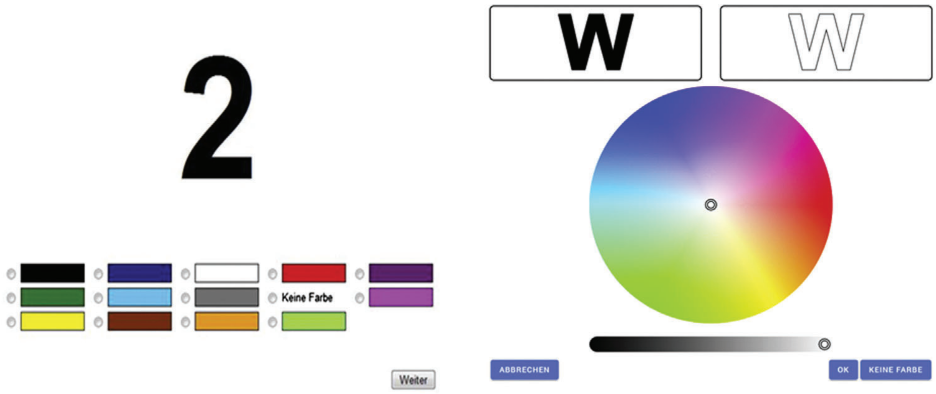

Fig. 2 Color picker tests to assess consistency of grapheme-color associations. Left: variant with thirteen colors (e.g., Simner et al., 2006b; Simner et al., 2009). Right: Variant with a fine grained color palette (cf. Eagleman et al., 2007).

responses to incongruent compared to congruent colors, while non-synesthetes do not show this effect (e.g., Odgaard et al., 1999; Mills et al., 1999; Dixon et al., 2004; Ward et al., 2007).

Synesthesia runs in families, although both the particular concurrents (e.g., the colors of a grapheme) and the types of synesthesia (e.g., grapheme-color, lexical-gustatory, etc.) that occur within a particular family can vary widely (Ward et al., 2005; Barnett et al., 2008a). Nevertheless, it has long been assumed that it has a genetic basis. Studies based on whole-genome linkage scans, exome sequencing and on family based linkage analysis support this assumption (Asher et al., 2009; Tomson et al., 2011; Tilot et al., 2018). These studies suggest that synesthesia is an oligogenic trait subject to multiple modes of inheritance and locus heterogeneity. Moreover, genes associated with axonogenesis may be etiologic for the hyper-connectivity that characterizes the neurobiology of synesthesia (Tilot et al., 2018).

Development of Synesthesia

Synesthetic associations are established early in childhood. According to the neonatal hypothesis of synesthesia (Maurer and Maurer, 1988), we all may have been synesthetes as young infants due to the increased functional connectivity in the infant brain. Synesthesia in adults may then be viewed as a result of incomplete pruning or decreased inhibition of feedback projections in early development. While there is evidence for exuberant anatomical connectivity and for arbitrary sensory cross-activations in young infants (Huttenlocher et al., 1982; Wagner and Dobkins, 2011), and while there are early sensory cross-activations which may survive in the form of cross-modal correspondences (Spector and Maurer, 2011), the neonatal hypothesis of synesthesia has been questioned recently (see Deroy and Spence, 2013, for a critical discussion). The fact that many types of synesthesia involve cultural artifacts hints to a later development, particularly at the age when language is established.

In a pioneering study, Simner et al. (2009) followed the development of grapheme-color synesthesia in children starting at the age of 6 years. In order to investigate the development of consistent synesthetic associations in real time, they sampled more than 600 children between the age of 6 and 7 years. To assess consistency, the children were presented with the letters of the alphabet and the digits 0–9, one by one, in a random order on a computer screen together with an on-screen palette of 13 colors (see **Fig. 1**). They were required to pair each grapheme with the "best" color. After the presentation of all the graphemes, there was a short break and then the same test was repeated again. By comparing the choices of the two tests, a consistency score was calculated for each child as the number of identical grapheme-color choices. On average, this consistency score was 3.5 out of 36 graphemes. Next, 47 children who had scores significantly higher than this mean score were identified as potential synesthetes and were retested in a second session one year later (i.e., at the age of 7/8 years). Using the same test procedure, Simner et al. identified eight children who scored highly consistent both within and across the two test sessions. The number of graphemes that triggered consistent synesthetic experiences increased with age from 10.5 in Session 1 to 16.9 in Session 2. In a follow-up study, Simner and Bain (2013) tested these children again at age 10/11. The results showed that five of the eight synesthetes identified in Simner et al. (2009) still conformed to the synesthesia criteria. Moreover, the number of consistent graphemes increased to 25.7. In contrast, the other three children did not conform to the criteria anymore. Overall, the results of these studies suggest that grapheme-color synesthesia can be assessed already in 6-year old children and that the number of consistent inducer-concurrent pairs increases with development.

Besides this empirical indication for the disappearance of synesthesia in childhood, there is also evidence for synesthesia attrition later in development. There are many anecdotal reports of cases that seem to have had synesthesia as children, but who have lost it during adolescence (Flournoy, 1893; Riggs and Karwoski, 1934; Cytowic, 1997; Emrich et al., 2000). Probably several critical or sensitive periods, that is, limited windows of time during development, during which the effect of experience on brain function is particularly strong, exist. These may include pruning during early development, acquisition of cultural artifacts between the age 3 and 7 (language, numbers, letter, musical notation, etc.) as well as activation and reorganization of neural circuits during adolescence (Sisk and Foster, 2004).

During the adult lifespan, synesthesia is characterized by a long period of stability with high consistency scores. However, in older age, there is evidence for an attenuation of the synesthetic experience, at least for some synesthetes (Meier et al., 2014; Simner et al., 2017).

Neural Basis of Synesthesia

On a neural level, there is a general consensus that the emergence of synesthesia is related to the connectivity between the brain areas involved in processing the inducer and those involved in processing the concurrent. This is particularly obvious for grapheme-color synesthesia, in which the grapheme processing area is adjacent to the color processing area in the temporal lobe. There is also converging evidence from functional (Nunn et al., 2002; Tang et al., 2008; Weiss et al., 2005; Hubbard and Ramachandran, 2005) and structural (Rouw and Scholte, 2007; Weiss and Fink, 2009) MRI studies that, in addition to temporal areas, parietal regions also play an important role in synesthesia. TMS studies have provided further evidence for the involvement of parieto-occipital areas (Esterman et al., 2006; Muggleton et al., 2007; Rothen et al., 2010). Specifically, they suggest that parieto-occipital regions are involved in synesthetic binding, and thus complement the crosstalk between the brain areas involved in processing the inducers and concurrents. Structural differences in terms of enhanced white matter tracts have been identified with diffusion tensor imaging and voxel-based morphometry (Rouw and Scholte, 2007; Weiss and Fink, 2009; Zamm et al., 2013). Moreover, there is evidence for globally-altered brain network topology (Hanggi et al., 2011) which seems to be consistent with imaging studies that have found activation differences (e.g., stronger blood-level-dependent responses) between synesthetes and non-synesthetes in retinotopic areas as well as in several other brain areas such as the frontal lobes and the precuneus (Hupe and Dojat, 2015).

Theories of Synesthesia

Based on the findings from structural and functional neuroimaging, two prominent theories, the cross-activation theory and the disinhibited feedback theory, have been formulated to account for the emergence of synesthesia. More recently, another theory, the stochastic resonance model has been introduced.

Cross-Activation Theory

The cross-activation theory suggests that synesthetic experiences are based on cross-activation between brain areas involved in processing the inducer, for example graphemes, and brain areas involved in processing the concurrent, for example, for colors (Hubbard et al., 2011; Ramachandran and Hubbard, 2001). It is based on the assumption that genetic factors lead to decreased pruning between these brain areas during development. The cross-activation theory was originally formulated to explain grapheme–color synesthesia and there is in fact evidence for stronger connectivity between the visual word form area and color processing area V4 (Rouw et al., 2011; Hubbard et al., 2011). There is also some evidence for the cross-activation theory in sound color synesthesia, that is, hyper-connectivity between the auditory cortex and V4 (Zamm et al., 2013). However, for other forms of synesthesia, such as sequence-space or lexical-gustatory, evidence for cross-activation is still less convincing and it is not clear whether differences between synesthetes and non-synesthetes can be explained by stronger anatomical pathways between brain areas involved for processing inducers and concurrents.

Disinhibited Feedback Theory

The disinhibited feedback theory suggest another possibility, namely that synesthesia is not based on hyper-connectivity per se, but arises due to disinhibited feedback from higher-order associative regions to sensory regions not originally activated by the inducing stimulus (Grossenbacher and Lovelace, 2001). According to this theory, processing a grapheme in the visual word form area activates parietal cortex which feeds back activation to V4. Disinhibited feedback theory can thus account for parietal cortex activations typically found in functional imaging studies of grapheme-color synesthesia. It also provides a mechanism for cases of drug-induced and acquired synesthesia and for the induction of synesthetic experiences by hypnosis (Luke and Terhune, 2013; Cohen Kadosh et al., 2009).

Stochastic Resonance Model

According to the stochastic resonance model by Lalwani and Brang (2019), synesthetic experiences emerge due to increased neural noise when processing the inducer. An increase in the input noise can result in an improvement in the output signal-to-noize ratio by synchronization between the neural systems involved in inducer and concurrent processing. Through repeated activation of the concurrent modality through stochastic resonance, the strength of connections between inducer and concurrent increase. According to this model, synesthetes have greater neural noise in sensory regions which allows pre-existing multisensory pathways to elicit supra-threshold activation which results in the synesthetic experience. This model may also provide for a more general framework to explain various types of synesthesia.

The three theories can be distinguished by the way the inducer and the concurrent are related. In the cross-activation theory, the link is direct and based on additional connections between the brain areas involved in processing the inducer and the concurrent in synesthetes. In the disinhibition theory, the link is indirect, mediated by higher cortical brain areas. Specifically, in synesthetes there is a lack of inhibition of activation from the higher cortical areas to the brain areas involved in processing the concurrent. In the stochastic resonance theory, synesthetes show a higher level of noise that is co-activated with the inducer, which leads to stochastic synchronization between activations in the brain areas involved in processing the inducer and the concurrent.

Associations Between Synesthesia and Perception, Cognition and Personality

Perception

Originally, it has been thought that synesthesia can be characterized as a perceptual phenomenon (Baron-Cohen et al., 1987; Laeng et al., 2004; Mattingley et al., 2001; Ramachandran and Hubbard, 2001). For example, Ramachandran and Hubbard (2001) used a visual search task to investigate whether synesthetic experiences are genuinely perceptual. They presented different geometric shapes consisting of the digits that triggered particular color experiences for a brief moment. The result showed that the synesthetes recognized more shapes than a control group suggesting a pop-out effect. Moreover, presenting a flanked grapheme in the periphery of the visual field evoked color even though the grapheme itself could not be identified. These results suggest that synesthesia occurs at an early stage of perceptual processing. This is consistent with findings based on event-related potentials which suggest that synesthetes differ in magno- and parvo-cellular processing, with synesthetes having a perceptual enhancement of the parvo-cellular system for high spatial frequency visual processing (Barnett et al., 2008b). In addition, grapheme-color synesthetes have a reduced phosphine-threshold when stimulated with transcranial magnetic stimulation, indicating that their visual cortex is hyper-excitable (Terhune et al., 2015). Moreover, grapheme-color synesthetes also perform better on tests of color perception (Banissy et al., 2009; Yaro and Ward, 2007).

On the other hand, there are findings that show that rather than percepts per se, the meaning, for example the concept of a number magnitude is sufficient to trigger synesthetic experiences. Research using ambiguous graphemes, for example a 2 that can be perceived as a Z or a 5 that can be perceived as an S, showed that depending on the context-appropriate interpretation, the same physical stimulus was perceived in a different color (Myles et al., 2003; Dixon et al., 2002). Moreover, when an arithmetic problem is presented (e.g., 5 + 2) and immediately afterward the color of a color patch must be named, naming times are faster when the synesthetic color of the solution to the calculation is congruent to the color patch (Dixon et al., 2000). These results suggests that activating the conceptual representation of an inducer is sufficient to trigger a synesthetic response. In fact, synesthetic experiences can even occur for imagined synesthetic inducers. Typically, the synesthetic inducer is conceptual, but the experience has a perceptual quality.

Imagery

In the domain of imagery, in general, synesthetes report more vivid visual imagery (Barnett and Newell, 2008; Meier and Rothen, 2013a; Price, 2009; Spiller and Jansari, 2008). In an experimental setting, grapheme-color synesthetes were faster than a matched control group on an imagery task that involved the generation and inspection of visual images (Spiller and Jansari, 2008). Similarly, synesthetes have been found to perform better on mental rotation tasks (Brang et al., 2013; Lunke and Meier, 2019).

In line, synesthesia is associated with a distinct profile of cognitive style (Meier and Rothen, 2013a). Using the Verbalizer-Visualizer Questionnaire, which involves three independent cognitive style dimensions (verbal, visual-spatial, vivid imagery), grapheme-color synesthetes showed higher ratings on both the verbal and vivid imagery style dimensions, but not on visual-spatial dimension. These results suggest that a preference for both a verbal and a vivid imagery visual style can co-occur within the same group of individuals. Graphemes, that is, the inducers, are instances of sequences and involve serial, analytic processing, favoring a verbal cognitive style. In contrast, colors (and visual forms) that is, the concurrents, involve parallel or holistic processing, thus favoring a vivid visual processing style.

Memory

Single case studies such as the famous case of the mnemonist Shereshevsky who was investigated by Luria (1968) have suggested that synesthetes may have an extraordinary memory. Shereshevsky was a multiple synesthete who used his synesthetic associations in combination with classical mnemonics to boost his memory in order to perform as a memory artist. His extraordinary memory abilities have been systematically documented by Luria (1968). There are several other case studies of synesthetes who showed excellent performance on some kinds of memory tests (Smilek et al., 2002; Mills et al., 2006). Group studies have qualified the general claims of an extraordinary memory by showing that synesthetes, in particular grapheme-color synesthetes, show advantages on some tests and for some materials (Lunke and Meier, 2018, Rothen and Meier, 2010a, see Meier and Rothen, 2013b, Rothen et al., 2012 for reviews). However, these advantages are generally in an ordinary range (defined as within one standard deviation of performance). Thus, they do not justify the claim that synesthesia per se leads to an extraordinary memory. Nevertheless, grapheme-color synesthetes show better memory for colors and, in particular their consistent representation of their very fine-grained synesthetic color associations suggests that they can be considered color memory experts.

Creativity

Many famous artists such as Kandinsky, Klee, van Gogh, Nabokov, Messiaen, and Duke Ellington are assumed to have had synesthesia. Accordingly, a link has been made between creativity and synesthesia. In line, several empirical studies have reported that synesthetes are more likely to work in creative professions such as art designer, musician, etc (Rich et al., 2005; Ward et al., 2008; Lunke and Meier, 2019). Moreover, higher prevalence of synesthesia among art students also suggests a link between synesthesia and an interest in creativity (Rothen and Meier, 2010b).

Findings based on psychometric tests of creativity show, however, a less consistent pattern with an advantage for synesthetes on some tests of creativity but not on others (Ward et al., 2008; Chun and Hupe, 2016; Lunke and Meier, 2019). Thus, while there is an indication of a link between synesthesia and creative occupations, the link between synesthesia and creativity on psychometric tests is less pronounced. Overall, this pattern of results only partially supports the notion that, from a phylogenetic perspective, enhanced creativity may have been the reason why the synesthesia gene has survived, a hypothesis brought forward by Ramachandran and Hubbard (2003).

Personality

In the domain of personality, studies that assessed the big five personality factors (i.e., neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness) showed a consistently relationship between synesthesia and higher scores on the openness of experience factor (Banissy et al., 2013; Chun and Hupe, 2016; Rouw and Scholte, 2016). Moreover, some findings indicate that synesthetes score lower on the agreeableness factor and the neuroticism factor (Banissy et al., 2013). The latter is consistent with a higher prevalence of anxiety disorder among synesthetes (Carmichael et al., 2019). Banissy et al. (2013) found that synesthetes scored higher on a fantasizing scale, which is related to the openness factor as well as to vividness of mental imagery.

In a related study, synesthesia was linked to increased schizotypy, suggesting that synesthesia may be associated with cognitive differences that extend beyond the synesthetic experiences (Banissy et al., 2012). In fact, previous studies have found a relation between positive schizotypy and creativity (Nelson and Rawlings, 2010). Similarly, creativity has been linked to heightened openness to experience (Furnham and Chamorro-Premuzic, 2004). Thus, there is some overlap between personality characteristics of synesthetes and personality characteristics of creative non-synesthetes. This is not surprising when one considers the relationship between synesthesia and creativity. Furthermore, the cognitive system involved in idea generation and creativity shares some commonalities with psychopathology. Highly creative people have an increased risk for mood disorders, schizophrenia spectrum disorders or alcoholism (Benson and Park, 2013; Carson, 2011). Whether or not there is a higher prevalence for these disorders in synesthesia is addressed in the next section.

Relationships to Clinical Disorders and Other Neurological Conditions

Conceptually, synesthesia can be viewed as related to schizophrenia, particular to hallucinations (i.e., the positive symptoms). Both involve a concurrent experience. However, while in synesthesia the inducer is conscious and the relationship between inducer and concurrent is consistent, hallucinations rather are considered to be the experience of a concurrent without inducer. Nevertheless it has been speculated that there may be a relationship between synesthesia and schizophrenia or at least between synesthesia and schizotypy (Banissy et al., 2012).

Tilot et al. (2019) investigated genetic links between grapheme-color synesthesia and neuropsychiatric traits. In a large sample of several hundred synesthetes, polygenic scores derived from published genome-wide scans of schizophrenia were compared to a control group of more than 2000 non-synesthetes. The results indicated a very slight, but still significant association between schizophrenia scores and synesthesia. Thus, the relationship between synesthesia and schizophrenia seems to be genetically determined. However, the results indicated little evidence for an increased risk of schizophrenia for synesthetes.

Another disorder that has often been linked to synesthesia is autism. Several studies have reported an overlap between the cognitive profile of synesthesia and autism and have suggested a genetic link (Hughes et al., 2017; Ward et al., 2017). Moreover, there is suggestive evidence for a higher prevalence of synesthesia among patients diagnosed with autism (Baron-Cohen et al., 2013; Neufeld et al., 2013). However, Tilot et al. (2019), who also compared genome-wide scans of autism spectrum disorder, found no significant association between autism and synesthesia. Therefore this study provides little support that the suggested link between autism and synesthesia is genetically determined.

Using family linkage analysis, Gregersen et al. (2013) found a close phenotypic and genetic relationship between absolute pitch and synesthesia. Absolute pitch refers to the ability to identify the pitch of isolated tones using musical pitch labels without comparing to any reference pitch. It is a rare phenomenon with an estimated prevalence lower than synesthesia. Interestingly, there seems to be a higher prevalence of synesthetes among absolute pitch possessors than in the general population (Gregersen et al., 2013). In fact, in absolute pitch, the tone can be considered as the inducer and the pitch label as the concurrent, which makes the link between the two conditions obvious. Concordantly, absolute pitch is also associated with enhanced connectivity (Brauchli et al., 2019; Loui et al., 2011).

Using a somewhat different methodological approach to assess associations between synesthesia and a large variety of clinical disorders, Carmichael et al. (2019) screened more than 3500 adults for synesthesia. They found 95 grapheme-color synesthetes among them, thus replicating the prevalence of 2%–4% for synesthesia in the general population. They also asked all the participants whether they had ever had a diagnosis for several clinical conditions. After exclusion of those conditions with a prevalence rate below 1%, these included allergies, anxiety disorder, asthma, attention deficit hyperactivity disorder, autism spectrum disorder, bulimia, depression, dyslexia, eczema, hay fever, insomnia, irritable bowel syndrome, migraine, obsessive-compulsive disorder, sleep apnea, and stomach ulcers. For each condition, Carmichael et al. (2019) tested whether they could be predicted by synesthesia. This was, in fact, the case for anxiety disorder and obsessive-compulsive disorder. Somewhat weaker associations were also found for allergies and autism spectrum disorder. Also of interest is the finding that neither attention deficit hyperactivity disorder, asthma, bulimia, depression, dyslexia, eczema, hay fever, insomnia, irritable bowel syndrome, migraine, sleep apnea nor stomach ulcers was associated with synesthesia. Among these latter results, the null finding of attention deficit hyperactivity disorder, irritable bowel syndrome, and migraine is particularly interesting, as there have also been preliminary evidence and speculations on their co-occurrence with synesthesia (Carruthers et al., 2012; Jonas and Hibbard, 2015).

Can Synesthesia be Acquired by Training?

Given that synesthesia is associated with desirable characteristics such as enhanced perception, memory and creativity, it may be interesting for non-synesthetes to acquire synesthesia by training. As synesthesia involves a genetic component however, it is likely that those who do not have the genetic predisposition cannot acquire synesthesia. Nevertheless, training studies have shown that it is possible to learn inducer-concurrent associations, for example between letters/numbers and specific colors. In fact, it is possible to mimic the synesthetic Stroop effect even after brief grapheme-color-association training (Meier and Rothen, 2009). More extended training has revealed that non-synesthete participants can be trained to an extent that they report color experiences at the end of the training (Bor et al., 2014; Rothen et al., 2018; Colizoli et al., 2012). However, critically, these experiences quickly disappeared again after the training (Rothen et al., 2018). Thus, there is no evidence that training can induce the profile that characterizes congenital synesthesia.

Summary

Synesthesia is a rare condition that is characterized by the conscious experience of stimulus attributes that are not present in a particular physical stimulus. The most often investigated variant is grapheme-color synesthesia, which involves the concurrent experience of a specific and consistent color when a digit or letter is presented. On a neural level, synesthesia goes together with hyperconnectivity in the brain. On a cognitive level, synesthesia, in particular grapheme-color synesthesia, is associated with an advantage in memory performance and higher creativity. Regarding personality features, synesthesia is related to higher levels of openness, schizotypy, and neuroticism. This is reflected in a genetic link with schizophrenia as well as a higher prevalence of anxiety disorders and obsessive-compulsive disorders among synaesthetes. Although associations between synesthetic inducers (e.g., letters) and concurrents (e.g., colors) can be learned intentionally and incidentally, the experiential and behavioral consequences are short-lived. Thus, synesthesia is best characterized as a congenital condition.

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