Synaesthesia

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Key Words

Synaesthesia · Crossed sensation · Hearing colours ·
Grapheme-colour synaesthesia

Abstract

Synaesthesia is the intriguing, involuntary experience of feeling one sensation in response to a different sensory stimulus. Recognised since described in 1890 by John Locke and clarified by Galton in the 1880s, it has been analysed in the last 50 years. Grapheme-colour synaesthesia is the commonest form, but many other sensory linkages are reported. Experiments show that it is a genuine immediate perception, not merely a memory or learned association. Many of the mechanisms posited are based on indirect methods, and we know little of the neurophysiological mechanisms.

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Synaesthesia is defined as the involuntary experience of a cross-modal linkage. For example, hearing a sound (the inducing stimulus) evokes the sensation of seeing a colour (concurrent perception).

In 1690, John Locke [1] described:

‘A studious blind man who bragged one day that he now understood scarlet was ... the sound of a trumpet.’

Synaesthetic experience is involuntary, reproducible from day to day, typically lifelong, and probably an inherited phenomenon, more common in women. Some synaesthetes have subtle evidence of left hemisphere dys-

function, but an eidetic memory is also a frequent accompaniment. Positron emission tomography studies of ‘coloured hearing’ demonstrate activation of colour processing areas in response to words. These areas normally associate perceptions of colour with other features of a visual stimulus, such as shape. Synaesthesia may therefore be a variant of normal brain activity.

Although synaesthesia was first investigated over 100 years ago by Galton [2–4], it has largely been regarded as a rarity or curiosity [5].

Galton [6] described many degrees of acuity of visual imagery in:

‘gentlemen who had this curious habit of invariably associating numbers with definite forms of mental imagery. It is a habit that is quite automatic, the form is frequently very vivid and sometimes very elaborate and highly coloured, and its origin is always earlier than those who see it can recollect. Those who visualise numerals in number-forms are apt to see the letters of the alphabet, the months of the year, dates, etc., also in forms; but whereas they nearly always can suggest some clue to the origin of the latter, they never can, or [p. 318] hardly ever can, to that of the numerals.’

A recent, personal visit to the country home of Sibelius, near Helsinki, disclosed that the famous composer would hear in his head the sound F major when he looked at his green fireplace, D major when looking at an adjacent, dominantly yellow picture and A major when he saw a blue object (coloured-hearing synaesthesia).

Galton estimated the prevalence of synaesthesia as 1 in 200 [4], but the most widely cited figure is 1 in 2,000 [7]. The evoked or concurrent sensation occurs *between modalities*, for example: seeing colours while listening to music or feeling tactile shapes while tasting foods [8]. Synaesthetes often experience correspondences between the shades of colour, tones of sounds and intensities of tastes that provoke alternate sensations. For instance, a synaesthete may see a more intense red as the pitch of a sound gets higher. These crossed sensations are not metaphorical associations; rather, they are involuntary and tend to persist through life. Synaesthesia can even occur when the primary sense is impaired or lost so that someone, for example, who sees colours in response to certain spoken words, may still see the colours if he subsequently becomes blind.

Grapheme-Colour Synaesthesia

The form of synaesthesia [9] most examined is that in which looking at letters or numbers evokes a sensation of colour. Graphemes can be numerals, letters, ideograms, punctuation marks and other glyphs. Ramachandran and Hubbard [10] studied 2 otherwise normal, synaesthetic subjects who 'saw' a specific colour every time they saw a specific number or letter. Four experiments showed that this was a genuine immediate perception, not merely a memory association. (i) The synaesthetically induced colours could lead to perceptual grouping, even though the inducing numerals or letters did not. (ii) Synaesthetically induced colours were not experienced if the graphemes were presented peripherally. (iii) Roman numerals were ineffective: the actual number grapheme (presumably Arabic numerals) was required. (iv) If 2 graphemes were alternated, the induced colours were also seen in alternation. However, colours were no longer experienced if the graphemes were alternated at more than 4 Hz.

Their obvious conclusion was that grapheme-colour synaesthesia arose from cross-wiring between the colour 'centre' and the number area, both located in the fusiform (temporo-occipital) gyrus. They also suggested a similar explanation for the representation of metaphors in the brain: hence, the higher incidence of synaesthesia among artists and poets [10].

Recently, Ward et al. [11] also reported 3 cases of synaesthesia who experienced colours in response to written musical notation, graphemes and music.

Stroop Effect

The Stroop effect is a demonstration of interference in the reaction time of a task. When a word such as blue, green or red is printed in a different colour from the colour named, e.g. the word 'red' is printed in green, the subject's reading of the word is delayed. Synaesthetes show Stroop-like interference when asked to name the colour of graphemes, but surprisingly not for written musical notes. This was the first empirical demonstration of synaesthesia for musical notation. The synaesthetic Stroop effects might arise from processing the meaning of a stimulus and not just as a result of verbal response interference. However, the colour associations themselves may have a developmental origin in the names assigned to them. In all 3 cases, the colours of the written notes are related to the graphemes that arbitrarily denote them (e.g. 'A' may be 'red' both as a letter and when written in musical notation). The results suggest that synaesthetic associations may migrate from one representational format (e.g. graphemes) to another (e.g. musical notation) [12].

It has been assumed that the colour-number linkage is unidirectional, e.g. numbers evoke a colour, but colours do not evoke numbers. In a random colour generation task, evidence shows [13] an implicit co-activation of digits by colours, i.e. a bidirectional link. This constrains neurological theories concerning cross-modal associations in general and synaesthesia in particular.

Variations of Synaesthesiae

Of the different types of synaesthesia, most have colour as the secondary sensation (see table 1); rarer are concurrent perceptions of smell or taste. Beeli, Esslen and Jancke [23] describe a musician who experienced different tastes in response to hearing different musical tone intervals, and who made use of her synaesthetic sensations in the complex task of tone-interval identification. Cytowic [24] wrote a pop psychology book entitled *The Man Who Tasted Shapes*.

A doctor recently told me that she was first, gradually aware of synaesthesiae when in her late 40s. She had no such experience earlier in life. When looking at or thinking of a calendar, she sees the weekends vertically lifted like a hump in the straight horizontal line (fig. 1). They appear 'in my mind's eye, on a flat board, coloured grey or brown.' She would particularly but not exclusively have this sensation at the time when her husband serving

Table 1. Descriptions of some famous synaesthetes

Name	Type of synaesthesia	Patient's description
Jean Sibelius, composer	Sound to colour	'Everything he saw produced a corresponding impression on his ear – every impression of sound was transferred and fixed as colour on the retina of his eye and thence to his memory. And this he thought as natural, with as good reason as those who did not possess this faculty called him crazy or affectedly original. For this reason he only spoke of this in the strictest confidence and under a pledge of silence. "For otherwise they will make fun of me!"' [14]
Nikolai Rimsky-Korsakov, composer	Musical keys to colour	Rimsky-Korsakov synaesthetically experienced colours for musical keys (musical keys to colour). For example, for him, the key of C major was white, and the key of B major was a gloomy dark blue with a steel shine. [15]
Amy Beach, pianist and composer	Musical keys to colour	'Amy's mother encouraged her to relate melodies to the colours blue, pink, or purple, but before long Amy had a wider range of colours, which she associated with certain major keys. Thus C was white, F-sharp black, E yellow, G red, A green, A-flat blue, D-flat violet or purple, and E-flat pink. Until the end of her life she associated these colours with those keys.' [16]
Tony DeCaprio, jazz-rock guitarist	Musical note to colour	'... as at least an aid in memory enhancement, I believe that the assignment of colours, which will correspond to respective notes in the twelve tone scale, can bring the musician that much closer to Super Symmetry. I do not speak about "blue notes" or "colour tones" here. I speak of a rather esoteric phenomena where my mind simply sees each note in a specific and recurring colour. I do not have a reason why I see notes as colours; I just do.' [17]
Duke Ellington, composer and pianist	Timbre to colour; tones to textures	'I hear a note by one of the fellows in the band and it's one colour. I hear the same note played by someone else and it's a different colour. When I hear sustained musical tones, I see just about the same colours that you do [sic], but I see them in textures.' [18]
Richard Feynman, physicist	Graphemes to colour	'When I see equations, I see the letters in colours – I don't know why. As I'm talking, I see vague pictures of Bessel functions from Jahnke and Emde's book, with light-tan j's, slightly violet-bluish n's, and dark brown x's flying around. And I wonder what the hell it must look like to the students.' [19]
Franz Liszt, composer	Musical tones to colour	'When Kapellmeister in Weimar (1842), he astonished the orchestra saying: "Oh please, gentlemen, a little bluer, if you please! This tone type requires it!" Or: "That is a deep violet, please, depend on it! Not so rose!" First the orchestra believed Liszt just joked; later they got accustomed to the fact that the great musician seemed to see colours there, where there were only tones.' [20]
Olivier Messiaen, composer and organist	Chord structure to colour sequences	'Many of his compositions, such as Oiseaux Exotiques, L'ascension, and Couleurs de la cite celeste, are directly based upon his, in a sense, trying to "produce pictures" via sound, writing specific notes to produce specific colour sequences and blends.' [21]
Vladimir Nabokov, author	Sound and shape to colour	'... the colour sensation seems to be produced by the very act of my orally forming a given letter while I imagine its outline. The long "A" of the English alphabet has for me the tint of weathered wood, but a French "A" evokes polished ebony. This black group also includes hard g (vulcanized rubber) and r (a sooty rag bag being ripped). Oatmeal n, noodle-limp l, and the ivory-backed hand mirror of o take care of the whites ... there is steely x, thunder-cloud z, and huckleberry k. Since a subtle interaction exists between sound and shape, I see q as browner than k, while s is not the light blue of c, but a curious mixture of azure and mother-of-pearl'. Nabokov's mother was a synaesthete, as were his wife and his son Dimitri Nabokov. [22]

abroad in the services and was to come home on weekend leave, and she was thinking about the days of the week. But, 'it occurred at other times and persists since his retirement. It is not psychological', she observes.

Nabokov [22] described colour sensation 'produced by the very act of my orally forming a given letter while I imagine its outline. The long "A" of the English alphabet has for me the tint of weathered wood ...' (see table 1).

Fig. 1. Patient's perception of weekend and weekdays in a normally aligned calendar.

Mechanisms

So-called modularists consider synaesthesia as the product of neural miswiring, for example between the visual and auditory areas [25]. Unitarists, however, consider synaesthesia as an emotional process of sensory perception located in the limbic system [24]. Differences in the placing of the experienced colours have been somewhat speculatively divided into either 'out in space' (projector synaesthetes) or 'in the mind's eye' (associator synaesthetes). For projector synaesthetes, naming the colour of the ink in which a grapheme was presented induced greater Stroop interference than naming the photism colour, whereas for associator synaesthetes, the opposite pattern was observed [26]. Ramachandran and Hubbard [10] conjectured that there might be 2 groups of synaesthetes, 'lower' (referring to lower perceptual processes) and 'higher' (referring to higher cognitive processes), in whom the different forms of synaesthesia represent different stages of brain processing. These authors predicted different synaesthetes would show different patterns of cerebral blood flow or evoked response. Another study [1] showed auditory word, but not tone, stimulation triggered synaesthesia. In both groups word stimulation compared with tone stimulation activated the classical language areas of the perisylvian regions.

Investigations

Synaesthetes, studied by positron emission tomography, activated several visual associative areas: the posterior inferior temporal cortex and the parieto-occipital junctions. The former has been implicated in the integration of colour with shape and in verbal tasks which require attention to visual features of objects to which words refer. Synaesthetes also showed activations in the right prefrontal cortex, insula and superior temporal gyrus.

Functional magnetic resonance imaging (fMRI) showed activity in visual cortical areas specifically relat-

ed to illusory coloured and spatially located visual percepts in a synaesthetic man who had been completely blind for 10 years. Late-blind or sighted non-synaesthetic controls showed no such differential activation [27]. When presented with Braille letters that elicited synaesthetic colours, activation was found in the fusiform gyrus in the late-blind synaesthete but not in a late-blind control subject. Nunn et al. [28], also using fMRI, located the region activated by speech in synaesthetes to area V4/V8 in the left hemisphere; they showed overlap with V4/V8 activation in normal controls in response to colour. No activity was detected in areas V1 or V2, the primary visual cortex, which is therefore unnecessary for such experience.

Hubbard and Ramachandran [29] suggest that cross-activation may occur between adjacent regions of the fusiform gyrus involved in letter recognition and colour processing, whereas higher synaesthesia may arise from cross-activation in the parietal cortex, particularly in the angular gyrus, the ventral intraparietal area and the lateral intraparietal area.

Cross-activation in the region of the parietal lobe might explain synaesthetic number forms, in which numerical (and other ordinal sequences) are experienced as having specific locations in space, in addition to colours [10, 29]. Since graphemes, phonemes, music and colours function in different brain regions, the several manifestations of synaesthesia probably have different anatomical neuronal substrates. But since affected members of one family with X-linked dominant inheritance showed different forms of synaesthesia, the various forms may share common neurophysiological mechanisms [30].

Conclusion

In studying this fascinating phenomenon, speculation is rife, and much of the literature is based on the indirect psychological techniques. What is clear is that the unusual linkage of sensory experience reflects an unusual,

aberrant cortico-cortical connectivity. This is probably founded in the embryonic evolution of the brain, but it can persist for long periods without the natural experience in the referred modality (e.g. in the blind) and therefore does not depend solely on memory or continuing

associative learning. Its anatomical substrate and synaptic mechanisms are poorly understood. Further investigations might yield a better understanding of other aspects of neuronal and synaptic physiology.

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