Synesthesia

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(Note: each letter and number is a “color”) How someone with synesthesia might perceive (not "see") certain letters and numbers. Synesthetes see characters just as others do (in whichever color actually displayed) but simultaneously perceive colors as associated with or evoked by each one.

Synesthesia (also spelled **synæsthesia** or **synaesthesia**; from the Ancient Greek σύν *syn*, "together", and αἴσθησις *aisthēsis*, "sensation") is a neurological phenomenon in which stimulation of one sensory or cognitive pathway leads to automatic, involuntary experiences in a second sensory or cognitive pathway.[1][2][3][4] People who report such experiences are known as synesthetes.

Difficulties have been recognized in adequately defining synesthesia:[5][6] Many different phenomena have been included in the term synesthesia ("union of the senses"), and in many cases the terminology seems to be inaccurate. A more accurate term may be ideasthesia.

In one common form of synesthesia, known as grapheme → color synesthesia or color-graphemic synesthesia, letters or numbers are perceived as inherently colored.[7][8] In spatial-sequence, or number form synesthesia, numbers, months of the year, and/or days of the week elicit precise locations in space (for example, 1980 may be "farther away" than 1990), or may appear as a three-dimensional map (clockwise or counterclockwise).[9][10]

Only a fraction of types of synesthesia have been evaluated by scientific research.[11] Awareness of synesthetic perceptions varies from person to person.[12]

Although synesthesia was the topic of intensive scientific investigation in the late 19th and early 20th centuries, it was largely abandoned by scientific research in the mid-20th century.[13] Psychological research has demonstrated that synesthetic experiences can have measurable behavioral consequences, and functional neuroimaging studies have identified differences in patterns of brain activation.[8] Many find that synesthesia aids the creative process.[*citation needed*] Psychologists and neuroscientists study synesthesia not only for its inherent appeal, but also for the insights it may give into cognitive and perceptual processes that occur in synesthetes and non-synesthetes alike.

Characteristics

There are two overall forms of synesthesia: **projecting** synesthesia and **associative** synesthesia. People who project will see actual colors, forms, or shapes when stimulated, as is commonly accepted as synesthesia; associators will feel a very strong and involuntary connection between the stimulus and the sense that it triggers. For example, in the common form chromesthesia (sound to color) a projector may hear a trumpet and see an orange triangle in space while an associator might hear a trumpet and think very strongly that it sounds "orange".

Some synesthetes often report that they were unaware their experiences were unusual until they realized other people did not have them, while others report feeling as if they had been keeping a secret their entire lives.[11] The automatic and ineffable nature of a synesthetic experience means that the pairing may not seem out of the ordinary. This involuntary and consistent nature helps define synesthesia as a real experience. Most synesthetes report that their experiences are pleasant or neutral, although, in rare cases, synesthetes report that their experiences can lead to a degree of sensory overload.[14]

Though often stereotyped in the popular media as a medical condition or neurological aberration, many synesthetes themselves do not perceive their synesthetic experiences as a handicap. To the contrary, some report it as a gift—an additional "hidden" sense—something they would not want to miss. Most synesthetes become aware of their distinctive mode of perception in their childhood. Some have learned how to apply their ability in daily life and work. Synesthetes have used their abilities in memorization of names and telephone numbers, mental arithmetic, and more complex creative activities like producing visual art, music, and theater.[11]

Despite the commonalities which permit definition of the broad phenomenon of synesthesia, individual experiences vary in numerous ways. This variability was first noticed early in synesthesia research.[15] Some synesthetes report that vowels are more strongly colored, while for others consonants are more strongly colored.[14] Self reports, interviews, and autobiographical notes by synesthetes demonstrate a great degree of variety in types of synesthesia, intensity of synesthetic perceptions, awareness of the perceptual discrepancies between synesthetes and non-synesthetes, and the ways synesthesia is used in work, creative processes, and daily life.[11][16]

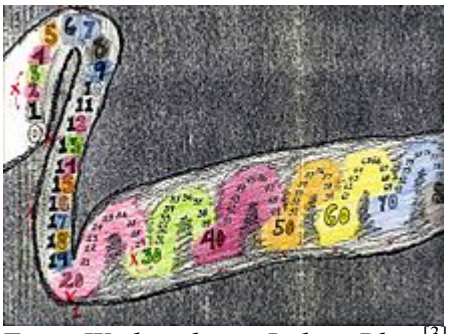
Synesthetes are very likely to participate in creative activities.[17] It has been suggested that individual development of perceptual and cognitive skills, in addition to one's cultural environment, produces the variety in awareness and practical use of synesthetic phenomena.[12][16]

Forms

Synesthesia can occur between nearly any two senses or perceptual modes, and at least one synesthete, Solomon Shereshevsky, experienced synesthesia that linked all five senses.[*medical citation needed*] Types of synesthesia are indicated by using the notation x → y, where x is the "inducer" or trigger experience, and y is the "concurrent" or additional experience. For example, perceiving letters and numbers (collectively called graphemes) as colored would be indicated as grapheme → color synesthesia. Similarly, when synesthetes see colors and movement as a result of hearing musical tones, it would be indicated as tone → (color, movement) synesthesia.

While nearly every logically possible combination of experiences can occur, several types are more common than others.

Grapheme-color synesthesia



From *Wednesday is Indigo Blue*.[3] Note this example's upside-down clock face.

In one of the most common forms of synesthesia, individual letters of the alphabet and numbers (collectively referred to as graphemes) are "shaded" or "tinged" with a color. While different individuals usually do not report the same colors for all letters and numbers, studies with large numbers of synesthetes find some commonalities across letters (e.g. A is likely to be red).[14]

As a child, Pat Duffy told her father, "I realized that to make an R all I had to do was first write a P and draw a line down from its loop. And I was so surprised that I could turn a yellow letter into an orange letter just by adding a line." Another grapheme synesthete says, "When I read, about five words around the exact one I'm reading are in color. It's also the only way I can spell. In elementary school I remember knowing how to spell the word 'priority' [with an "i" rather than an "e"] because ... an 'e' was out of place in that word because 'e's were yellow and didn't fit."[18]

Chromesthesia

Another common form of synesthesia is the association of sounds with colors. For some, everyday sounds such as doors opening, cars honking, or people talking can trigger seeing colors. For others, colors are triggered when musical notes and/or keys are being played. People with synesthesia related to music may also have perfect pitch because their ability to see/hear colors aids them in identifying notes or keys.[*citation needed*]

The colors triggered by certain sounds, and any other synesthetic visual experiences, are referred to as *photisms*.

According to Richard Cytowic,[3] chromesthesia is "something like fireworks": voice, music, and assorted environmental sounds such as clattering dishes or dog barks trigger color and firework shapes that arise, move around, and then fade when the sound ends. Sound often changes the perceived hue, brightness, scintillation, and directional movement. Some individuals see music on a "screen" in front of their faces. For Deni Simon, music produces waving lines "like oscilloscope configurations – lines moving in color, often metallic with height, width and, most importantly, depth. My favorite music has lines that extend horizontally beyond the 'screen' area."

Individuals rarely agree on what color a given sound is. B flat might be orange for one person and blue for another. Composers Liszt and Rimsky-Korsakov famously disagreed on the colors of music keys.

Spatial sequence synesthesia

Those with spatial sequence synesthesia (SSS) tend to see numerical sequences as points in space. For instance, the number 1 might be farther away and the number 2 might be closer. People with SSS may have superior memories; in one study, they were able to recall past events and memories far better and in far greater detail than those without the condition. They also see months or dates in the space around them. Some people see time like a clock above and around them.[*unreliable medical source?*][19][20]

Number form

A number form from one of Francis Galton's subjects (1881).[9] Note how the first 12 digits correspond to a clock face.

A number form is a mental map of numbers that automatically and involuntarily appears whenever someone who experiences number forms thinks of numbers. Number forms were first documented and named in 1881 by Francis Galton in "The Visions of Sane Persons".[21]

Auditory-tactile synesthesia

In auditory → tactile synesthesia, certain sounds can induce sensations in parts of the body. Auditory → tactile synesthesia may sometimes originate from birth or be acquired sometime later in life.[*citation needed*] It is one of the least common forms of synesthesia.[22]

Ordinal linguistic personification

Main article: Ordinal linguistic personification

Ordinal-linguistic personification (OLP, or personification for short) is a form of synesthesia in which ordered sequences, such as ordinal numbers, days, months and letters are associated with personalities (Simner & Hubbard 2006). Although this form of synesthesia was documented as early as the 1890s (Flournoy 1893; Calkins 1893) researchers have, until recently, paid little attention to this form (see History of synesthesia research). Ordinal personification normally co-occurs with other forms of synesthesia such as grapheme-color synesthesia.

Misophonia

Misophonia is a neurological disorder in which negative experiences (anger, fright, hatred, disgust) are triggered by specific sounds. Richard Cytowic suggests that misophonia is related to, or perhaps a variety of, synesthesia.[23] Miren Edelstein and her colleagues have compared misophonia to synesthesia in terms of connectivity between different brain regions as well as specific symptoms. They formed the hypothesis that "a pathological distortion of connections between the auditory cortex and limbic structures could cause a form of sound-emotion synesthesia."[24]

Mirror-touch synesthesia

This is a rare form of synesthesia where individuals feel the same sensation that another person feels (such as touch). For instance, when such a synesthete observes someone being tapped on their shoulder, the synesthete involuntarily feels a tap on their own shoulder as well. People with this type of synesthesia have been shown to have higher empathy levels compared to the general population. This may be related to the so-called mirror neurons present in the motor areas of the brain, which have also been linked to empathy.[25]

Lexical-gustatory synesthesia

This is another rare form of synesthesia where certain tastes are experienced when hearing words. For example, the word basketball might taste like waffles. The documentary 'Derek tastes like earwax' gets its name from this phenomenon, in references to pub owner James Wannerton who experiences this particular sensation whenever he hears the name spoken.[26][27] It is estimated that 0.2% of the population has this form of synesthesia.[28]

Other forms

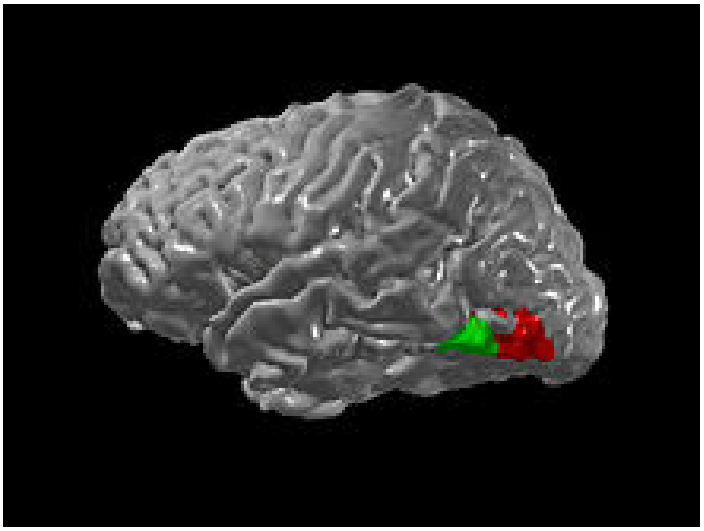
Other forms of synesthesia have been reported, but little has been done to analyze them scientifically. These include associating people or emotion with colors, sounds to objects, letters to objects, and many more.

Cause

Little is known about how synesthesia develops. The first studies of synesthesia in children and its development are currently undergoing.

Based on the findings that synesthesia is not a phenomenon of crossed senses but has the properties of ideasthesia, it was proposed[29] that synesthesia develops during childhood at the time at which children are for the first time intensively engaged with abstract concepts. This hypothesis—referred to as *semantic vacuum hypothesis*—explains why the most common forms of synesthesia are grapheme-color, spatial sequence and number form: These are usually the first abstract concepts that educational systems require children to learn.

Mechanism



Regions thought to be cross-activated in grapheme-color synesthesia (green=grapheme recognition area, red=V4 color area).[30]

Dedicated regions of the brain are specialized for given functions. Increased cross-talk between regions specialized for different functions may account for the many types of synesthesia. For example, the additive experience of seeing color when looking at graphemes might be due to cross-activation of the grapheme-recognition area and the color area called V4 (see figure).[30] This is supported by the fact that grapheme-color synesthetes are able to identify the color of a grapheme in their peripheral vision even when they cannot consciously identify the shape of the grapheme.[30]

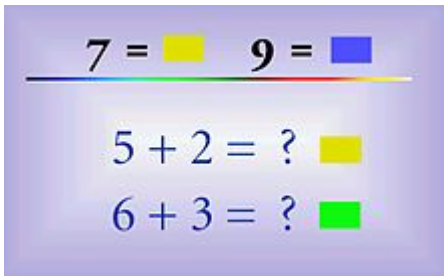
An alternate possibility is disinhibited feedback, or a reduction in the amount of inhibition along normally existing feedback pathways.[31] Normally, excitation and inhibition are balanced. However, if normal feedback were not inhibited as usual, then signals feeding back from late stages of multi-sensory processing might influence earlier stages such that tones could activate vision. Cytowic and Eagleman find support for the disinhibition idea in the so-called acquired forms[3] of synesthesia that occur in non-synesthetes under certain conditions: temporal lobe epilepsy, head trauma, stroke, and brain tumors. They also note that it can likewise occur during stages of meditation, deep concentration, sensory deprivation, or with use of psychedelics such as LSD or mescaline, and even, in some cases, marijuana.[3] However, synesthetes report that common stimulants, like caffeine and cigarettes do not affect the strength of their synesthesia, nor does alcohol.[3]:137–40

A very different theoretical approach to synesthesia is that based on ideasthesia. According to this account, synesthesia is a phenomenon mediated by the extraction of the meaning of the inducing stimulus. Thus, synesthesia may be fundamentally a semantic phenomenon. Therefore, to understand neural mechanisms of synesthesia the mechanisms of semantics and the extraction of meaning need to be understood better. This is a non-trivial issue because it is not only a question of a location in the brain at

which meaning is "processed" but pertains also to the question of understanding—epitomized in e.g., the Chinese room problem. Thus, the question of the neural basis of synesthesia is deeply entrenched into the general mind–body problem and the problem of the explanatory gap.[32]

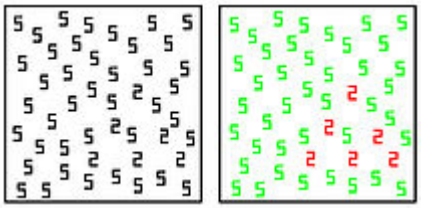
Diagnostic criteria

Although often termed a "neurological condition," synesthesia is not listed in either the DSM-IV or the ICD since it most often does not interfere with normal daily functioning.[33] Indeed, most synesthetes report that their experiences are neutral or even pleasant.[14] Like perfect pitch, synesthesia is simply a difference in perceptual experience.



Reaction times for answers that are congruent with a synesthete's automatic colors are faster than those whose answers are incongruent.[3]

The simplest approach is test-retest reliability over long periods of time, using stimuli of color names, color chips, or a computer-screen color picker providing 16.7 million choices. Synesthetes consistently score around 90% on reliability of associations, even with years between tests.[1] In contrast, non-synesthetes score just 30–40%, even with only a few weeks between tests and a warning that they would be retested.[1]


The automaticity of synesthetic experience. A synesthete might perceive the left panel like the panel on the right.[30]

Grapheme-color synesthetes, as a group, share significant preferences for the color of each letter (e.g. A tends to be red; O tends to be white or black; S tends to be yellow etc.)[14] Nonetheless, there is a great variety in types of synesthesia, and within each type, individuals report differing triggers for their sensations and differing intensities of experiences. This variety means that defining synesthesia in an individual is difficult, and the majority of synesthetes are completely unaware that their experiences have a name.[14]

Neurologist Richard Cytowic identifies the following diagnostic criteria for synesthesia in his *first* edition book. However, the criteria are different in the second book:[1][2][3]

1. Synesthesia is involuntary and automatic.
2. Synesthetic perceptions are spatially extended, meaning they often have a sense of "location." For example, synesthetes speak of "looking at" or "going to" a particular place to attend to the experience.
3. Synesthetic percepts are consistent and generic (i.e. simple rather than pictorial).
4. Synesthesia is highly memorable.
5. Synesthesia is laden with affect.

Cytowic's early cases mainly included individuals whose synesthesia was frankly projected outside the body (e.g. on a "screen" in front of one's face). Later research showed that such stark externalization occurs in a minority of synesthetes. Refining this concept, Cytowic and Eagleman differentiated between "localizers" and "non-localizers" to distinguish those synesthetes whose perceptions have a definite sense of spatial quality from those whose perceptions do not.[3]

Epidemiology

Depending on the study, researchers have suggested 1 in 2,000 people have some form of synesthesia, while others have reported 1 in 300 or even as many as 1 in 23. One problem with statistics is that some individuals will not self-classify as they do not realize that their perceptions are different from those of everyone else.[30]

Grapheme-color, chromesthesia, or anything color-related, appear to be the most common forms of synesthesia, they have a prevalence rate of 64.4% in the synesthesia population. Some studies have found that color related grapheme can account for 86%. Time related words-colour synesthesia is the second most common with a prevalence rate of 22%-62%. Music-color is also prevalent at 18%, some studies found that music-color was shown in 41% of patients. Some of the rarest are reported to be auditory-tactile, mirror-touch, and lexical-gustatory. [34]

There is research to suggest that the likelihood of having synaesthesia is greater in people with autism.[35]

History

Main article: History of synesthesia research

The interest in colored hearing dates back to Greek antiquity, when philosophers asked if the color (*chroia*, what we now call timbre) of music was a quantifiable quality.[36] Isaac Newton proposed that musical tones and color tones shared common frequencies, as did Goethe in his book, "Theory of Color."[*citation needed*] There is a long history of building color organs such as the clavier à lumières on which to perform colored music in concert halls.[37][37][38]

The first medical description of "colored hearing" is in an 1812 German thesis by the German physician Sachs.[39] The "father of psychophysics," Gustav Fechner, reported the first empirical survey of colored letter photisms among 73 synesthetes in 1876,[40][41] followed in the 1880s by Francis Galton.[9][42][43] C.G.Jung refers to "colour hearing" in his Symbols of Transformation in 1912.[44] Research into synesthesia proceeded briskly in several countries, but due to the difficulties in measuring subjective experiences and the rise of behaviorism, which made the study of *any* subjective experience taboo, synesthesia faded into scientific oblivion between 1930 and 1980.

As the 1980s cognitive revolution made inquiry into internal subjective states respectable again, scientists returned to synesthesia. Led in the United States by Larry Marks and Richard Cytowic, and later in England by Simon Baron-Cohen and Jeffrey Gray, researchers explored the reality, consistency, and frequency of synesthetic experiences. In the late 1990s, the focus settled on grapheme → color synesthesia, one of the most common[14] and easily studied types. Synesthesia is now the topic of scientific books and papers, Ph.D. theses, documentary films, and even novels.

Since the rise of the Internet in the 1990s, synesthetes began contacting one another and creating web sites devoted to the condition. These early grew into international organizations such as the American Synesthesia Association, the UK Synaesthesia Association, the Belgian Synaesthesia Association, the Canadian Synesthesia Association, the German Synesthesia Association, and the Netherlands Synesthesia Web Community.

Society and culture

Artistic investigations

Vision by Carol Steen; Oil on Paper; 15x12-3/4" 1996. A representation of a synesthetic photism experienced during acupuncture.

Main article: Synesthesia in art

Synesthetic art historically refers to multi-sensory experiments in the genres of visual music, music visualization, audiovisual art, abstract film, and intermedia.[11][13][45][46][47][48] Distinct from neuroscience, the concept of synesthesia in the arts is regarded as the simultaneous perception of multiple stimuli in one gestalt experience.[49]

Neurological synesthesia has been a source of inspiration for artists, composers, poets, novelists, and digital artists. Nabokov writes explicitly about synesthesia in several novels.[*citation needed*] Kandinsky (a synesthete) and Mondrian (not a synesthete) both experimented with image-music congruence in their paintings. Scriabin composed colored music that was deliberately contrived and based on the circle of fifths, whereas Messiaen invented a new method of composition (the modes of limited transposition) specifically to render his bi-directional sound-color synesthesia. For example, the red rocks of Bryce Canyon are depicted in his symphony *Des canyons aux étoiles* ("From the Canyons to the Stars"). New art movements such as literary symbolism, non-figurative art, and visual music have profited from experiments with synesthetic perception and contributed to the public awareness of synesthetic and multi-sensory ways of perceiving.[11]

Contemporary artists with synesthesia, such as Carol Steen[50] and Marcia Smilack[51] (a photographer who waits until she gets a synesthetic response from what she sees and then takes the picture), use their synesthesia to create their artwork. Brandy Gale, a Canadian visual artist, experiences an involuntary joining or crossing of any of her senses - hearing, vision, taste, touch, smell and movement. Gale paints from life rather than from photographs and by exploring the sensory panorama of each locale attempts to capture, select, and transmit these personal experiences.[52][53][54]

Literary depictions

Main articles: Synesthesia in literature and Synesthesia in fiction

Synesthesia is sometimes used as a plot device or way of developing a character's inner life. Author and synesthete Pat Duffy describes five ways in which synesthetic characters have been used in modern fiction.[55][56]

1. Synesthesia as Romantic ideal: in which the condition illustrates the Romantic ideal of transcending one's experience of the world. Books in this category include *The Gift* by Vladimir Nabokov.
2. Synesthesia as pathology: in which the trait is pathological. Books in this category include *The Whole World Over* by Julia Glass.
3. Synesthesia as Romantic pathology: in which synesthesia is pathological but also provides an avenue to the Romantic ideal of transcending quotidian experience. Books in this category include Holly Payne's *The Sound of Blue.*
4. Synesthesia as psychological health and balance: *Painting Ruby Tuesday* by Jane Yardley, and *A Mango-Shaped Space* by Wendy Mass.

5. Synesthesia as young adult literature and science fiction: *Ultraviolet* by R.J. Anderson, and "One Is Not A Lonely Number" by Evelyn Krieger (YM Books, 2010).

Many literary depictions of synesthesia are not accurate. Some say more about an author's interpretation of synesthesia than the phenomenon itself.[*citation needed*]

Notable cases

Main article: List of people with synesthesia

Identifying synesthesia in the historical record is fraught with error unless (auto)biographical sources explicitly give convincing details.

There are many famous synesthetes, most of whom are artists, writers, or musicians. David Hockney perceives music as color, shape, and configuration and uses these perceptions when painting opera stage sets (though not while creating his other artworks). Russian painter Wassily Kandinsky combined four senses: color, hearing, touch, and smell.[1][3] Vladimir Nabokov described his grapheme-color synesthesia at length in his autobiography, *Speak, Memory*, and portrayed it in some of his characters.[57] Synesthetic composers include Duke Ellington,[58] Nikolai Rimsky-Korsakov,[59] and Olivier Messiaen, whose three types of complex colors are rendered explicitly in musical chord structures that he invented.[3][60] Physicist Richard Feynman describes his colored equations in his autobiography, *What Do You Care What Other People Think?*[61]

Other notable synesthetes include musicians Billy Joel,[62]:89, 91 Itzhak Perlman,[62]:53 Alexander Frey, Ida Maria,[63] Brian Chase[64][65] and Patrick Stump; actress Stephanie Carswell (credited as Stéphanie Montreux); inventor Nikola Tesla;[66] electronic musician Richard D. James aka Aphex Twin (who claims to be inspired by lucid dreams as well as music); and classical pianist Hélène Grimaud. Drummer Mickey Hart of The Grateful Dead wrote about his experiences with synaesthesia in his autobiography *Drumming at the Edge of Magic*.[*citation needed*] Pharrell Williams, of the groups The Neptunes and N.E.R.D., claims to experience synesthesia[67][68] and used it as the basis of the album *Seeing Sounds*. Singer/songwriter Marina and the Diamonds experiences music → color synesthesia and reports colored days of the week.[69]

Some artists frequently mentioned as synesthetes did not, in fact, have the neurological condition. Alexander Scriabin's 1911 *Prometheus*, for example, is a deliberate contrivance whose color choices are based on the circle of fifths and appear to have been taken from Madame Blavatsky.[3][70] The musical score has a separate staff marked *luce* whose "notes" are played on a color organ. Technical reviews appear in period volumes of *Scientific American*.[3] On the other hand, his older colleague Nikolai Rimsky-Korsakov (who was perceived as a fairly conservative composer) was, in fact, a synesthete.[71]

French poets Arthur Rimbaud and Charles Baudelaire wrote of synesthetic experiences, but there is no evidence they were synesthetes themselves. Baudelaire's 1857 *Correspondances* introduced the notion that the senses can and should intermingle. Baudelaire participated in a hashish experiment by psychiatrist Jacques-Joseph Moreau and became interested in how the senses might affect each other.[11] Rimbaud later wrote *Voyelles* (1871), which was perhaps more important than *Correspondances* in popularizing synesthesia. He later boasted *"J'inventais la couleur des voyelles!"* (I invented the colors of the vowels!).[*citation needed*]

Daniel Tammet wrote a book on his experiences with synesthesia called *Born on a Blue Day*.[72]

Joanne Harris, author of *Chocolat*, is a synesthete who says she experiences colors as scents.[73] Her novel *Blueeyedboy* features various aspects of synesthesia.

Research

Tests like this demonstrate that people do not attach sounds to visual shapes arbitrarily. Which shape would you call "Bouba" and which "Kiki?"

Research on synesthesia raises questions about how the brain combines information from different sensory modalities, referred to as crossmodal perception or multisensory integration.

An example of this is the bouba/kiki effect. In an experiment first designed by Wolfgang Köhler, people are asked to choose which of two shapes is named *bouba* and which *kiki.* 95% to 98% of people choose *kiki* for the angular shape and *bouba* for the rounded one. Individuals on the island of Tenerife showed a similar preference between shapes called *takete* and *maluma.* Even 2.5 year-old children (too young to read) show this effect.[74] Recent research indicated that in the background of this effect may operate a form of ideasthesia.[75]

Researchers hope that the study of synesthesia will provide better understanding of consciousness and its neural correlates. In particular, synesthesia might be relevant to the philosophical problem of qualia,[4][76] given that synesthetes experience extra qualia (e.g. colored sound). An important insight for qualia research may come from the findings that synesthesia has the properties of ideasthesia,[5] which then suggest a crucial role of conceptualization processes in generating qualia.[29]

Technological applications

Synesthesia also has a number of practical applications, one of which is the use of 'intentional synesthesia' in technology.[77]

Synesthesia and virtual reality

One type of application is the pain-reducing virtual reality program.[78] In existing programs, the main purpose is to reduce pain when undergoing a specific treatment by shifting the attention from the experienced pain to the virtual program in which the patient is participating. By using artificial synesthesia and combining various senses, this can help to enhance the control of a person's attention, which can be used to improve and direct sensory distraction from the perceived pain.

For example, many treatments for burn pain and wounds may increase patients' anxiety, which increases perceived pain. Shifting attention from pain and anxiety is therefore an important part of the treatment process.[79] Virtual reality has proven to be very effective in managing this acute pain in several medical settings by shifting patients' attention from their experienced pain to the program in which they have been introduced. It appears to be far more effective than other distraction techniques, like playing video games.[80] More specifically, the convergence of many sense modalities (e.g. sound, sight, and touch) gives patients the perception of being immersed in the virtual environment, which helps them endure the pain while relying less on pharmacological therapy.

The Voice

Peter Meijer developed a sensory substitution device called The vOICe (the capital letters "O," "I," and "C" in "vOICe" are intended to evoke the expression "Oh I see"). The vOICe is a privately owned research project, running without venture capital, that was first implemented using low-cost hardware in 1991.[81] The vOICe is a visual-to-auditory sensory substitution device (SSD) preserving visual detail at high resolution (up to 25,344 pixels).[82] The device consists of a laptop, head-mounted camera or computer camera, and headphones. The vOICe converts visual stimuli of the surroundings captured by the camera into corresponding aural representations (soundscapes) delivered to the user through headphones at a default rate of one soundscape per second. Each soundscape is a left-to-right scan, with height represented by pitch, and brightness by loudness.[83] Default resolution of the soundscape is 176×64. Therefore, it is roughly comparable to a retinal implant or brain implant with 10,000 electrodes.

The process of converting greyscale camera images into soundscapes works according to three simple rules. The first is 'left and right' in which left-to-right scanning results in hearing the stereo pan from left to right correspondingly. If there is a visual pattern on the left, the user hears a sound on the left, and similarly for the right. The second rule is 'up and down': every scan provides a pitch that indicates elevation. The higher the position of the visual pattern, the higher the pitch. The third and final rule is 'dark and light': loudness corresponds to brightness. The louder the sound, the brighter the visual pattern.

Silence indicates no light stimuli, the loudest sounds represent white light, and everything in between is a shade of grey.

For example, a straight bright line on a dark background, running from the top left to the bottom right, would sound like a tone steadily decreasing in pitch; a dot would sound like a short beep; and two dots would sound like two short beeps. Since real-life images are much more complex, there is also much more to hear through this device. While converting the visual pattern into a sound, the device uses a predictable real-time audio and video processing algorithm, allowing users to listen to and then interpret the visual information captured by a digital video camera. The vOICe compensates for the loss of vision by converting information from the lost sensory modality into stimuli in a remaining modality.[84]

This could lead to synthetic vision with truly visual sensations through crossmodal sensory integration through training and education. It requires a certain amount of time and effort to become proficient at differentiating objects, identifying objects, and locating them in space. Users are therefore advised to start training in a safe, familiar home environment in order to integrate the novel stimuli with other senses.

One of the remaining questions in this ongoing research concerning the vOICe is to what extent the use of a sensory substitution system can lead to visual sensations through forms of induced artificial synesthesia.