Synaesthesia and synergy in art. Gustav Mahler's "Symphony No. 2 in C minor" as an example of interactive music visualization

13

Johannes Deutsch*

Contents

Abstract

Synaesthesia occurs when stimulation of one sensory modality induces an experience in another sensory modality. This phenomenon can involuntarily emerge or be intentionally induced by artists through the synthesis of image or color and music. Consequently in the present chapter the author differentiates between the emergence of synaesthesia, understood as a neurological condition characterized by exceptional sensory perception and investigated in medicine, psychology, and recently in the neurosciences, and a long-standing tradition of synaesthetic œuvres in the history and theory of art and culture.

Johannes Deutsch
Ölzeltgasse 1/3
1030 Vienna, Austria
e-mail: office@johannes-deutsch.at

In science, synaesthesia is conceived as an involuntary experience which is perceptual in quality and not simply a form of imagery. The author follows this pathway of investigation from Gustav Theodor Fechner (1876, 1898), Sir Francis Galton (1880 a, b, c; 1883), Alfred Binet (1892) to recent research by Richard Cytowic (2002; Cytowic and Eagleman 2009), Vilayanur S. Ramachandran (Ramachandran and Hubbard 2001 a, b), Simon Baron-Cohen (1994; Baron-Cohen, Wyke, and Binnie 1987; Baron-Cohen and Harrison 1997), Hinderk Emrik (Emrik, Schneider, and Zedler 2002), and Julia Simner (2009). Although in synaesthesia connections between perceptions may also involve other senses like olfaction and taste, the most commonly investigated link is between auditory and visual perception. Recently, Baron-Cohen and colleagues have developed valid and reliable measures for the diagnosis of visual synaesthesia (Asher et al. 2006), as well as Eagleman for synaesthesia in general (Eagleman et al. 2007).

* I have a special debt of gratitude to my son "Chris" Léon Deutsch for his accurate scrutinizing and translating the widespread historical French literature on the relationship between vision and audition, from the early synergy between music and colors to the case reports as well as the literary elaborations of the "audition colorée".

Although some artists refer to their involuntary perceptual experience of synaesthesia, in the history and theory of art and culture synaesthesia is largely conceived of as the intentional effort to evoke sensory experiences in the audience, mainly through the synergy of music and colors (unidirectional – like in the neurological condition of synaesthesia – from the music to the colors). The author explores this long-standing history in aesthetics which connects colors to music from the Pythagoreans, through Leonardo da Vinci, the French "audition colorée", Alexander Skriabin, Wassily Kandinsky, the "sonchromatoschope" of Alexander László, to the most recent efforts in contemporary art and design.
Up to now, a major problem of realization for both the theoreticians of culture and art as well as the artists, was how to precisely recreate the simultaneity of synaesthetic perceptions so characteristic of synaesthesia as a neurological condition.
What follows shows how the author reached this goal in both avant-garde projects and in operas like Wagner's "Rheingold" and Schumann's "Manfred". Subsequently the ways in which Mahler's "Symphony No. 2 in C minor", also known as "Resurrection," was visualized are explained from both the aesthetic and the technical point of view. Regarding the technical realization, a complex computer cluster was adopted to generate real-time visualization. The cluster simultaneously processed and implemented any modulations picked up from the orchestra as nuances of the live interpretation of the music before translating them directly into visual variations.
The present chapter concludes with major theoretical questions concerning the frequency of occurrence of processes such as cross sensory coupling, the prevalence of fixed paired patterns of association as well as their relevance for art.

1. Synaesthesia as a neurological condition

In science, synaesthesia is understood as an involuntary experience which is perceptual in quality – and not simply a form of imagery – correlating to a neurological condition and seemingly having a genetic basis (Asher et al. 2009). However, imagery may additionally occur (Barnett and Newell 2008). During perceptual or cognitive activities (listening to music, reading, etc.) experiences of colors or taste automatically emerge. Synaesthetes see colors when hearing sounds ("music-color synaesthesia", Ward et al. 2006), or perceive tastes in their mouth when reading or hearing words ("lexical-gustatory synaesthesia", Simner and Ward 2006), or perceive spatial forms when reading time units (hours of the day, days of the week, months of the year, etc.) or numbers and letters ("visuo-spatial synaesthesia" and "grapheme synaesthesia", Simner 2009). A triggering stimulus termed "inducer" causes (as an effect) a secondary sensory experience termed "concurrent" (Grossenbacher and Lovelace 2001). Although in synaesthesia connections between perceptions may also involve other senses such as olfaction, or touch, the most commonly investigated relationship is the link between auditory and visual perception, especially "colored hearing" ("audition colorée") and "musical" color hearing (Cytowic 2002).

The historical pathway of investigations in synaesthesia can be traced from Gustav Theodor Fechner, Sir Francis Galton, and Alfred Binet to the contemporary research of Richard Cytowic, Vilayanur S. Ramachandran, Simon Baron-Cohen, Hinderk Emrik, and Julia Simner. Synaesthesia has been studied in medicine and psychology as a disturbance of sensory perception for about three centuries but the number of investigations increased notably between 1860 and 1930. The involuntary association of verbal sounds or phonemes, in particular vowel sounds, with colors was reported in psychology in the 19th Century. Synaethesia research began with case studies reported by Gustav Theodor Fechner (1876), Sir Francis Galton

(1880a, b, 1883), and Alfred Binet (1892; Binet and Philippe 1892; Beaunis and Binet 1892).

Gustav Theodor Fechner investigated color synaesthesia in his "Vorschule der Ästhetik" (1876). In the later editions (e.g., 2nd edition 1898) of his treatise he also included a number of clinical case studies drawing from clinical reports of Eugen Bleuler and Karl Lehman (Bleuler and Lehman 1881). In 1913, Bleuler published a book entitled „Zur Theorie der Sekundärempfindungen" devoted to synaesthetic perception (Bleuler 1913).

Having been concerned with the question of visualized numerals (Galton 1880a, b), a "visuo-spatial synaesthesia" or "grapheme synaesthesia", the psychologist Sir Francis Galton widely discussed color-hearing in his "Inquiries into human faculty and its development" (1883). Galton published a diagram of a colored alphabet, according to which A is yellow, E is green, O is red, etc. He had to cope with a non-existent consensus regarding the color attributed to each vowel and consonant, but having already investigated the relation of synaesthesia with mental imagery (Galton 1880c), Galton reported, not without perplexity, that "when the account of one seer is submitted to another seer, who is sure to see the colors in a different way, the latter is scandalized and almost angry at the heresy of the former." (Galton 1883, p. 111) The large individual differences, which puzzled Galton and other scientists of his time, have currently become the object of systematic inquiry in their own right (Dixon et al. 2004; Dixon and Smilek 2005; Day 2007).

The renowned French psychologist Alfred Binet published a number of case studies (1892; Binet and Philippe 1892; Beaunis and Binet 1892) also remarking that even if science considers synaesthesia as a mere disturbance of sensory perception, poets value it as a new form of art (Binet 1892). Indeed, la "Revue Philosophique" published not only Binets's case studies, but a veritable explosion of case reports (Lauret and Duchaussoy 1887; Henri 1893; Philippe 1893; Claparède 1900; Daubresse 1900; Sokolov 1901; Ulrich 1903, among others). Further, medical and psychological journals in French speaking countries devoted studies to the phenomenon (Cornaz 1851; Chabalier 1864; Flournoy 1892; Clavière 1898; Lemaitre 1904, among others) and books appeared on the topic as well (e.g., Baratoux 1888; Suarez de Mendoza 1890; Flournoy 1893).

A few years later, the Viennese psychoanalyst Hermine von Hug-Hellmuth as well as the Swiss psychoanalyst Oskar Pfister also seemed attracted to investigations on audition evocating colors (von Hug-Hellmuth 1912; Pfister 1912).

As early as 1893, psychologists such as the French Edouard Gruber began trying to objectify synaesthesia by means of questionnaires (e.g., Gruber 1893) or by discriminating between authentic synaesthesia and intermodal analogy (Bos 1929). But in the course of the 20th Century, behaviorist psychology increasingly focused its efforts on observable behavior, whereas subjective experiences no longer seemed suitable for scientific research. With regards to the time prior to the behavioristic turn in psychology, Georg Anschütz (Anschütz 1925, 1926, 1927, 1931, 1936) as well as Albert Wellek (Wellek 1927, 1931a, b) are worth mentioning for their final remarkable scientific efforts in synaesthesia research of this period. For a long time thereafter, the scientific community neglected the phenomenon synaesthesia, until it was rediscovered in the 1980s. Two special issues of the journal "Cortex" attested the increasing presence of synaesthesia in cognition research: in 2006 "Cognitive neuroscience perspectives on synaesthesia", and in 2009 "Synaesthesia and visuo-spatial forms" ("Cortex" 2006, 2009).

Recently, Baron-Cohen and colleagues have developed valid and reliable measures for the diagnosis of visual synaesthesia: "Methods of diagnosing synaesthesia have undergone tremendous changes since the time of the original case report. Emphasis is shifting to a deeper analysis of synaesthetic percepts, the genetic of synaesthesia and the neural mechanisms underlying the condition." (Asher et al. 2006, p. 146) Furthermore, the neuroscientist David Eagleman created the "Synaesthesia Battery" as a diagnostic instrument and the "Texsyn Toolbox" to be used with any form of synaesthesia (Eagleman et al. 2007).

Twenty years ago synaesthesia appeared to be quite rare: the neurologist Richard Cytowic estimated the ratio between synaesthetes and non-synaesthetes to be 1:25 000 (Cytowic 1989); around 1996 Baron-Cohen and colleagues gave a ratio of 1:2000 (Baron-Cohen et al. 1996); in 2010 Julia Simner of the University of Edinburgh suggested the currently accepted frequency of synaesthesia to be 1:23 (Metzger 2010). In such a case synaesthesia can no longer be considered an exceptional sensory phenomenon.

Synaesthesia of a particular person does not change over time but is highly consistent within each individual, independent from context, automatic, and involuntary (Baron-Cohen et al. 1993). The subject is aware that the inducer is – for example – an acoustic perception (e. g., music) and that the concurrent secondary perception is a visual experience (e. g., color). Could this indicate that synaesthesia does not imply a simple merging of the sensory functions, but more complex processes? Synaethetes are usually also able to distinguish their ordinary from their synaesthetic percepts. In the same person the link between inducer (e. g., A) and concurrent (e. g., red) is an experience constant over time, whereas there are very different forms of synaesthesia (about 150 types are known) in different individuals. From Day's (2007) demographic enquiry the types of synaesthesia shown in Table 1 are the most common.

Table 1 The most common types of synaesthesia according to Day's (2007) demographic enquiry

INDUCER	CONCURRENT	PERCENTAGE
grapheme	color	64,9
time unit	color	23,1
music	color	19,5
noise	color	14,9
phoneme	color	9,2
musical note	color	9
odor	color	6,8
taste	color	6,3
noise	taste	6,1
pain	color	5,5
people	color	5,4
touch	color	4,0

Visual synaesthetes are termed "associators" if their synaesthetic experience (e. g., color) is experienced in their "mind's eye"; for other visual synaesthetes, called "projectors", the synaesthetic perception (e. g., color) is projected outside (e. g., the concurrent color overlays the inducer, e. g., letter or numeral) (Dixon et al. 2004).

Especially in grapheme-color synaesthesia, the question arises whether the concurrent color experience is primarly determined by the form of the inducer grapheme (letter or numeral) or by their meaning. Ramachandran and Hubbard (2001b) suggested that the meaning of the inducer is not really relevant for triggering the concurrent experience, but a recent study showed that it may play a key role. According to Dixon and colleagues, for any inducer grapheme presented the concurrent color emerges independent from any variations in size or font (the meaning of the grapheme triggers the color, rather than its form) and ambiguous graphemes induce different concurrent colors, depending on whether they are read and understood as numeral or letters (Dixon et al. 2006). The debate on the relative role of meaning and form in grapheme-color synaesthesia led to two concurrent approaches to synaesthesia in science: (i) the cross-linkage, cross-activation, or "cross-talk" model, and (ii) the feedback model which will be discussed in what follows.

(i) Synaesthesia may be caused by a cross-wiring of areas in the brain, which would not normally be connected or only weakly linked. Consequently, the cross-activation model assumes that the areas of the brain that process graphemic forms such as numerals or letters (fusiform gyrus) are cross-linked to the areas of the brain that process color (fusiform areas) (Ramachandran and Hubbard 2001a, b).

(ii) The alternative model additionally postulates a direct feedback from areas of the brain that process meaning to areas that process color (Grossenbacher and Lovelace 2001; Dixon et al. 2004).

Looking for the actual neural roots of synaesthesia, Frith argued: "Brain imaging studies have shown that, in comparison to normal controls, people with colour-word synaesthesia do indeed show activity in 'visual' areas of the brain. By delineating the function of these visual areas more precisely we shall gain an understanding of the nature of this purely experiential phenomenon in physiological terms." (Frith 2001, pp. 156–159; see also Cytowic and Eagleman 2009)

Research on color experience triggered by spoken words using magnetic resonance imaging (fMRI) provided evidence that synaesthetic perceptions activate the same regions that support veridical perception. In the reported experiment, synaesthetic experiences of color activated the color-selective region V4 (Nunn et al. 2002). Hubbard and Ramachandran (2005) later validated these results. However, in March 2010 at the UK-Synaesthesia Congress in Brighton, the neuroscientist Jean-Michel Hupé (CerCo, CNRS, University of Toulouse) presented a study questioning the results of Nunn and Hubbard and claiming that he and his co-workers could not replicate the results (Hupé 2010; cf. Metzger 2010; see also Hupé et al. 2010). Further research may be required.

The neurological condition of synaesthesia is significantly represented in children. In 2006, Julia Simner asked: "What form do linguistic synaesthesias take before language acquisition? For example, is there a progression from sound-color, to phoneme-color, to grapheme-color synaesthesia during language and literacy acquisition?" (Simner 2006, p. 28) A recent study (Simner et al. 2009) provided evidence that the prevalent form among children is grapheme-color synaesthesia, which emerges along a developmental path following environmental exposure to learned linguistic units. The involvement of learned units showed that the grapheme-color synaesthesia emerged only after the acquisition of the inducer, and not from the moment of the birth.

Do results of synaesthesia-research allow drawing conclusions about the general average population? A major question remains whether synaesthetes and average population share the same neuronal processing. A number of studies provide evidence "that synaesthetes occupy an extreme end of a shared continuum on which non-synaesthetes also lie. [. . .] independent evidence shows that synaesthetic experiences reflect mechanisms found in all people, albeit to a different level of awareness." (Simner 2009, p. 1142) Therefore the associations of synaesthetes seem to rely on processes that are also present in the average population, with the difference that for synaesthetes such associations are available to consciousness. In grapheme-colors synaesthesia both synaesthetes, who experienced colors from inducers such as letters and/or numerals, and non-synaesthetes prefer certain pairings between letters and colors: “A” to red, “S” to yellow, “X” to black (Simner et al. 2005). Regarding the music-color synaesthesia Ward and colleagues (2006) indicate the tendency of synaesthetes to see lighter colors from high frequency sounds, and the same pairing between luminance and pitch is apparent in average population when making intuitive music-color associations.

2. Synaesthesia as the artist’s effort to evoke sensory experiences through the synergy of music and colors

Although a few artists may rely on their own involuntary perceptual experience as synaesthetes, in the history and theory of art and culture synaesthesia refers mainly to intentional efforts of the artist to evoke sensory experiences in the audience, mostly through the synergy of music and colors. Sound indeed refers to multisensory attributes not only in synaesthetic experience, but even under average perceptual conditions. Therefore, studies on the multisensory content of sound provide a deep insight into the complexity of auditory perception (Haverkamp 2007, 2009b, 2010).

Since the early 20th century, the successful pairing music and color (and even spatial forms) began due to increasing advances of technology. But the relationship between color and sound relies on a long-standing tradition of theoretical reflections on this topic as well as on various practical attempts to realize it. Exploring this history in aesthetics linking colors to music one can start with the Pythagoreans and continue with Leonardo da Vinci, the French “audition colorée”, and composers such as Alexander Scriabin. Ingenious inventors of color instruments such as the “sonchromatoscope” of Alexander László, painters like Wassily Kandinsky, and the most recent efforts in contemporary art and design are part of this history as well.

It is possible to construct correlations between perceptions and physical properties. Thus the frequency (wavelength) of light can be paired with the frequency (pitch) of a given pure tone by means of mathematical calculations. Over the centuries, philosophers, musicians, painters, as well as theoreticians have looked for the perfect match of pitch and color. As early as the 6th Century BC the Pythagoreans introduced the theory of “harmony” supervening to the universe. In the spirit of mathematical harmony, Pythagoreans created the diatonic scale (“Pythagorean”) where the ratio between the highest and the lowest pitch (frequency) is 2:1, which produces the interval of an octave. Musical harmony correlated to the cosmic order (the seven planets known at the time) and had an equivalent in the seven colors (Moritz 1987, 2006). In the 4th Century BC, Aristotle’s colors scale in “On sense and sensible objects” included seven colors: white, yellow, red, purple, green, blue, and black (Aristotle 1936). His scale corresponded to the tone intervals of the “Pythagorean” musical scale providing the basis for the relationship between color and sound in the ancient world (Jewanski 1999).

At the beginning of the 18th Century Isaac Newton provided experimental evidence that white light is composed of the seven colors of the spectrum (Newton 1704). According to Newton the mathematical-physical correspondence between the frequency of the tones and the much higher frequencies of the light waves could be calculated by introducing a coefficient. The ancient philosophical relation between color and sound therefore seemed to be validated by applying the laws of physics (Jewanski 1999; Topper 1999).

In his "Chromatography", Field (1835) suggested that painters should follow musicians with regard to harmony, and he provided a diagram linking the scale of color and the diatonic musical scale. In the same vein, Hay (1836) presented a scale pairing music to colors in his "The laws of harmonious coloring adapted to interior decorations, manufactures and other useful purposes".

Poets were interested in the link between sound and colors as well. In his poem "Voyelles" ["Vowels"] (1871), Arthur Rimbaud related the vowels of the alphabet to colors, proposing an intentional constructed relationship – termed "correspondance" ["correspondence"] – between sensory perceptions instead of an involuntary neuropsychological mechanism. A forerunner of the French program of the "correspondence" can be found in William Shakespeare's "A midsummer night's dream". The dream of Nick Bottom, the weaver, magnificently linked all senses: "The eye of man hath not heard, the ear of man hath not seen, man's hand is not able to taste, his tongue to conceive, nor his heart to report, what my dream was." (Shakespeare 1926 [1594–96], p. 58) Similarly, Charles Baudelaire's sonnet "Correspondances" in "Les fleurs du mal" ["The flowers of evil"] (1857) announced his program of the "correspondences", thereby paving the way for Rimbaud's proposal:

> "Comme des longs échos qui de loin se confondent
> Dans une ténébreuse et profonde unité,
> Vaste comme la nuit et comme la clarté
> Les parfums, les couleurs et les sons se répondent. "
>
> "As the long echoes, shadowy, profound,
> Heard from afar, blend in a unity,
> Vast as the night, as sunlight's clarity,
> So perfumes, colours, sounds may correspond."
> (Baudelaire 1993 [1857], p. 19)

Inspired by Baudelaire's program, Rimbaud created his sonnet "Voyelles" ["Vowels"], later collected in his volume "Poésies":

> "A noir, E blanc, I rouge, U vert, O bleu: voyelles [. . .]"
> "A black, E white, I red, U green, 0 blue: vowels [. . .]"
> (Rimbaud 2001 [1971], p. 135)

Indeed, in the course of the sonnet the vowel "I" becomes purple and the vowel "O" violet, whereas in synaesthesia as a neurological condition, the pairing between vowel and color is not only automatic, involuntary, and independent from context, but also remains a highly consistent fixed pattern within each individual for his or her entire life. In "Une saison en enfer" Rimbaud explicitly strengthened the intentionality of his project in the second paragraph "Alchimie du verbe" ["Alchemy of the word"] of its chapter "Délires II" ["Second delirium"]:

> "J'inventai la couleur des voyelles! – A noir, E blanc, I rouge, O bleu, U vert. Je réglai la forme et le mouvement de chaque consonne, et, avec les rythmes instinctifs, je me flattai d'inventer un verbe poétique accessible, un jour ou l'autre, à tous les sens."
>
> "I invented the colour of vowels!– A black, E white, I red, 0 blue, U green.–I organized the shape and movement of every consonant, and by means of instinctive rhythms, flattered myself that I was the inventor of a poetic language, accessible sooner or later to all the senses."
> (Rimbaud 2001 [1973], p. 235)

The poet aimed to extend the "correspondences" between sound and color to the other senses like touch and smell as well.

Let us now move to efforts in the past to translate theories linking color and music into practice. As early as 1500 Leonardo da Vinci projected colored light in the rhythm of music (Moritz 1987, 2006). At the court of the emperor Rudolf II, Giuseppe Arcimboldo built a sort of "color-piano" in order to support his assumption that an intimate relationship existed between heard musical sounds and perceived colors reaching from black to white (Moritz 1987). In the 18th Century, the Jesuit Louis Bertrand Castel followed Newton in suggesting that each tone (and not each interval) corresponds to a specific color. He developed an "ocular harpsichord", which was a color piano emanating colored light with every key pressed (Castel 1725, 1726a, b, 1751; Moritz 1987). It consisted "of a 6-foot square frame above a normal harpsichord; the frame contains 60 small windows each with a different colored-glass pane and a small curtain attached by pullies to one specific key, so that each time that key would be struck, that curtain would lift briefly to show a flash of corresponding color." (Moritz 1997, p. 1) From Castel's work grew a rich tradition of "color pianos" and "color organs". One example is the well known instrument of the English painter Alexander Wallace Rimington (Rimington 1911; Moritz 1987, 1997; Peacock 1988; Scheel 2006) who also provided his own "chromatic assignment". Rimington (1911) correlated a scale with twelve colors to one octave divided into 12 intervals. The most low-pitched tone (C) was paired with red, the color perceived when stimulated with the lowest frequency (longest wavelength) of visible light ("C = red").

The Russian composer Alexander Scriabin, who was said to be a "genuine" synaesthete, linked musical tones to colors in his symphony "Promethée. Le poème du feu. Op. 60" ["Prometheus. A poem of fire. Op. 60"] (1910) where he also included a part to be played by a color instrument, "clavier à lumières" ["light piano"] or "luce" ["light"], designed specifically for the performance of his tone poem. His light piano was played like a conventional piano, but it was mute and projected colored light onto a screen. It was a "Chromola", exclusively built in New York for the performance at the Carnegie Hall under the personal supervision of Preston S. Miller, at the time president of the "Illuminating Engineering Society" (and not – as sometimes reported – a color instrument of Rimington). William Moritz vividly describes the "moving lights that accompanied the 1915 New York premiere of Scriabin's synaesthetic symphony 'Prometheus. A poem of fire'. Scriabin wanted everyone in the audience to wear white clothes so that the projected colors would be reflected on their bodies and thus possess the whole room." A particularly bright light radiating at the acme of the symphony deeply impressed the audience and was even perceived as painful (Scriabin 1995 [1911]; Baker 1986; Moritz 1997).

Arnold Schönberg's "The fortunate hand. Drama with music" (1910–1914) merged colors, gestures, movements, light and music. It was first performed in Vienna in 1924. According to Schönberg, gestures, colors, and light had to be handled by the composer as if they were tones; figures and shapes were formed from individual light values and shades of color, resembling the forms, figures and motives with which musicians make music (Weibel 1987; Bidaine 2004).

A complementary effort was that of the painter Wassily Kandinsky in his tone drama "The yellow sound" (1909). It was first published in 1912 in "The Blue Rider Almanac", yellow being for Kandinsky the colour of middle-C on a piano (Kandinsky 1994). According to Kandinsky, colors correspond to the keyboard, eyes to the harmonies, and the soul to the piano with many strings, and he conceived of the painter as the hands that plays, touching the keys, in order to evoke vibrations in the soul. Kandinsky played with the harmonic connection of "musical tone and its movement, bodily-mental sound and its movement, and color-tone and its movement" (Weibel 1987). In "Concerning the spiritual in the art" (1911), he presented his own theory on color and synaesthesia (Kandinsky 2001 [1911]).

But in painting it was not only Kandinsky who was deeply concerned with synaesthesia, as several other painters interested in links between sensory perceptions can be cited. In 1913, a painter of Futurism, Enrico Prampolini published "Chromophony. The color of sounds", a chromophonic Manifesto according to which colors are the equivalent of tones and paintings corresponded to musical œuvres (Prampolini 1913). His celebrated painting "Simultaneous landscape" (1922) is also a magnificent attempt to capture sensory correspondences. Like Baudelaire and Rimbaud had earlier in literature, Futurism – this time stemming from painting – showed again the tendency to gradually extend the link between seeing and hearing to further sensory modalities. Thus Filippo Tommaso Marinetti and Luigi Enrico Colombo Fillia presented the "Manifesto of the futurist cuisine" (1930), a veritable program of cross sensory coupling (taste, touch, smell, vision – especially color-vision – as well as music-hearing). Consequently, Marinetti published his own "The futurist cookbook" (1989 [1932]). Both books deeply influenced Daniel Spoerri's contemporary "Eat Art" (Lemke 2006).

Regarding the particular synergy between hearing and seeing, a Centre Pompidou's exhibition "Sounds and light. A history of sound in the arts of the 20th century" (2004–2005) showed the synaesthetic program to be an undertaking of wide scope. It was clear that major painters such as Frantisek Kupka, Francis Picabia, Paul Klee, Piet Mondrian, Giacomo Balla, as well as many other renowned other artists, adhered to the synaesthetic program of the time (Bidaine 2004).

The long-standing tradition of "color-pianos" culminated in Alexander László's „sonchromatoscope" (1925) which enabled the accompaniment of piano music by projections. It consisted of a switchboard connected to four large and four small color projectors and was fitted with keys and levers like a sort of harmonium. This gave control over the projectors as well as the mixing of colors and images. László used slides, abstract forms, and colored light (Moritz 1997; Jewanski 1997; Scheel 2006), and correlated his color-harmonics with musical tonic intervals, therefore constructing an eight-step scale (László 1925).

Among the composers dealing with synaesthesia a few more can be briefly mentioned. Nicolai Rimski-Korsakov maintained the link between music and colors; Olivier Messiaen considered sounds deeply paired with colors moving with the music (Messiaen 1948; Johnson 1982; Nichols 1986; Samuel 1994); and finally György Ligeti, perhaps one of the few confirmed synaesthetes, linked his compositions of noises to shapes and colors, explicitly and accurately testifying to the phenomenology of his own perceptions in interviews (Ligeti 1958, 1983).

In the early 1930s, the steady ascent of film obscured the previous interest of audience and critics in color instruments, and a history of the relationship between music and film began. Between 1921 and 1967, Oskar Fischinger created about thirty visual music films, first without sound, later with sound and colors (Moritz 1997). After 1945 synaesthetic art movements arose such as "Happening" and "Fluxus" – both deeply inspired by Fischinger –, as well as the already mentioned "Eat Art" of Daniel Spoerri, and not least the "Theatre of Orgies and Mysteries" of Hermann Nitsch, one of the "Vienna Actionists". Nitsch further conceived a synaesthetic design for sets and costumes staging Jules Massenet's opera "Hérodiade" (Nitsch 1995).

This tendency to link hearing and seeing did not remain confined to avant-garde, but reached the popular contemporary club scene: from DJ to VJ. VJing – as a DJ does with music pieces – applies technology advances to mixing electronic music and moving images, which are generated separately. However, this genre soon transcended its popular field of origin by merging with design, architecture, and art (Behne 1987; Scheel 2006; Fischer 2008).

A further effort at going beyond the link between audition and vision in order to involve all sensory modalities is apparent in the field of design. In the 1920s, already the Bauhaus attempted synaesthetic correlations between design and architecture (Düchting 1996). The heritage of the intentional synaesthetic program of art and culture has carried on through to synaesthetic design (Riccò 1999, 2008).

Michael Haverkamp has been studying synaesthesia also as a neurological condition in order to apply its principles to engineering automobiles (Haverkamp 2009a) or other objects of every day life. He explained how the perceptual system aims to identify physical objects by generating perceptual objects. If that physical object is already known and represented in memory, its cross sensory attributes can be recalled by stimulation of only one modality: "learning to handle physical objects of daily life requires testing of all sensory properties like vision, audition, smell, taste, surface structure, hardness, and many others." (Haverkamp 2009b, p. 3)

Interactive real-time processes of contemporary media art not merely represent a substantial new development, but a significant shift in synaesthetic design feasibility. Through real-time interactivity, one art form can simultaneously react with another art form. The visual design enables us to create vision evoking analogies to each musical passage. In addition, for the first time advanced software makes real-time interaction possible so that the live performance and the unique subjective interpretation of the music associated with it can shape and modify this visual design. This synergy of art forms allows a highly concentrated and direct access to multisensory art perception.

3. Visualizing Mahler's "Symphony No. 2 in C minor"

Some of the author's own projects are conceived as synaesthetic œuvres. They comprise of avant-garde projects such as "Gesichtsraum" ["FaceSpace"] (Deutsch 2002; Maresch 2010; Zuckriegl 2010), as well as the visualization and staging of operas like Wagner's "Rheingold" (Binder 2004; Deutsch 2004, 2006a; Scheel 2006; Trenks 2005; Waltz 2008; Winkler 2005, 2006) or Schumann's "Manfred" (von Leliwa 2010). Another example of a synaesthetic œuvre is the landscape art project "Der unsichtbare Garten" ["The invis-

Fig. 1 Das Rheingold (Virtual Realm of the Gods), Donner and Wotan, the tempest in Scene 4, Concert performance at Brucknerhaus Linz, 2004

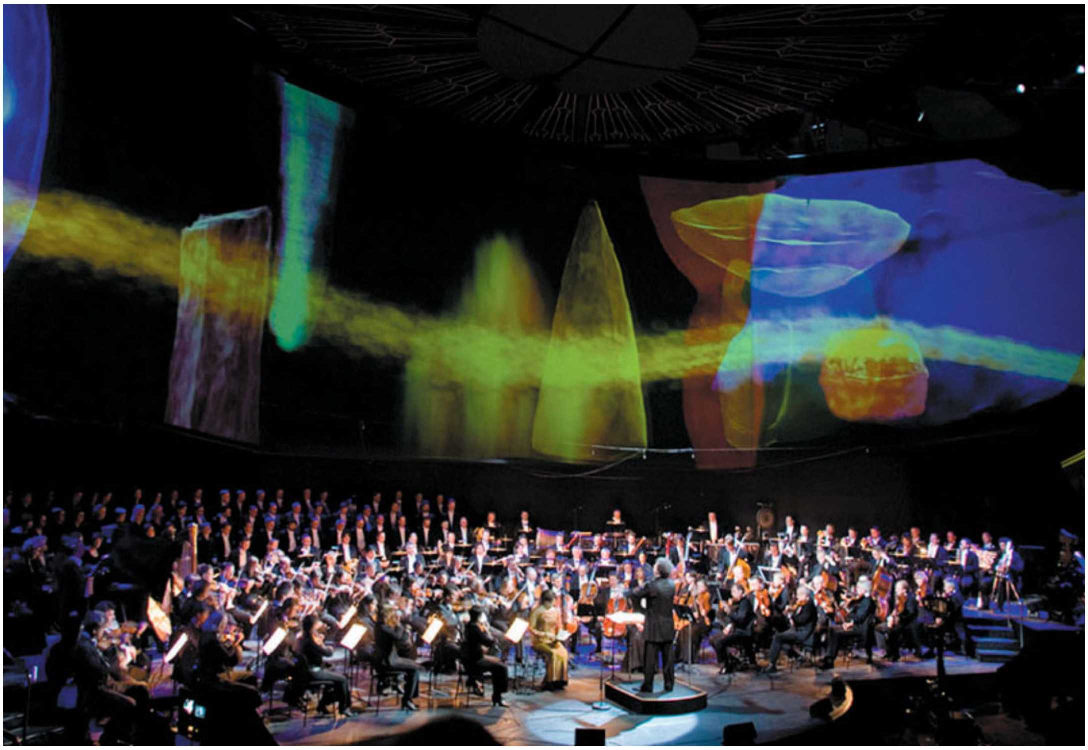

Fig. 2 Gustav Mahler "Symphony No. 2 in C minor", II. Movement, Concert performance at Philharmonic Concert Hall of Cologne, 2006

ible garden"] (Deutsch 2010, 2011). This is, however, not only a garden for visually impaired people, but rather one in which visually impaired people can bring new sensory perceptions to the sighted and where visually impaired and sighted people can exchange experiences. To enable this to happen, every visitor must put on a blindfold before entering the garden and then be led through it under the expert guidance of a visually impaired person. The garden provides a synaesthaetic link between touching and smelling the leaves on the trees, as well as the pairing of these perceptions with the hearing of the leaves' movement: "Within it the non-visual senses (touch, smell etc.) are exposed – along a determined route – to the various young trees from the region which have been chosen for their tactile, olfactory and acoustic potential." (Deutsch 2010, p. 21; Deutsch 2011)

The idea behind the presentation of a symphonic work like Mahler's "Symphony No. 2 in C minor", also known as "Resurrection", as a live and visually interactive performance was to create a new way to present classical music in media (Deutsch 2006c, 2008; Pelzmann 2008).[1] The media concept created for this live concert, for broadcast on television, and additionally for two films (Deutsch 2006b, 2007), sought to answer the questions such as how interactive media are able to create artistic content alongside classical music and how an artistic experi-

1 Commissioned by the WDR, West German Broadcast Corporation to mark its 50th anniversary, for both a gala concert given at the Kölner Philharmonie (Philharmonic Concert Hall of Cologne) and the live broadcast on television on the 1st of January 2006.

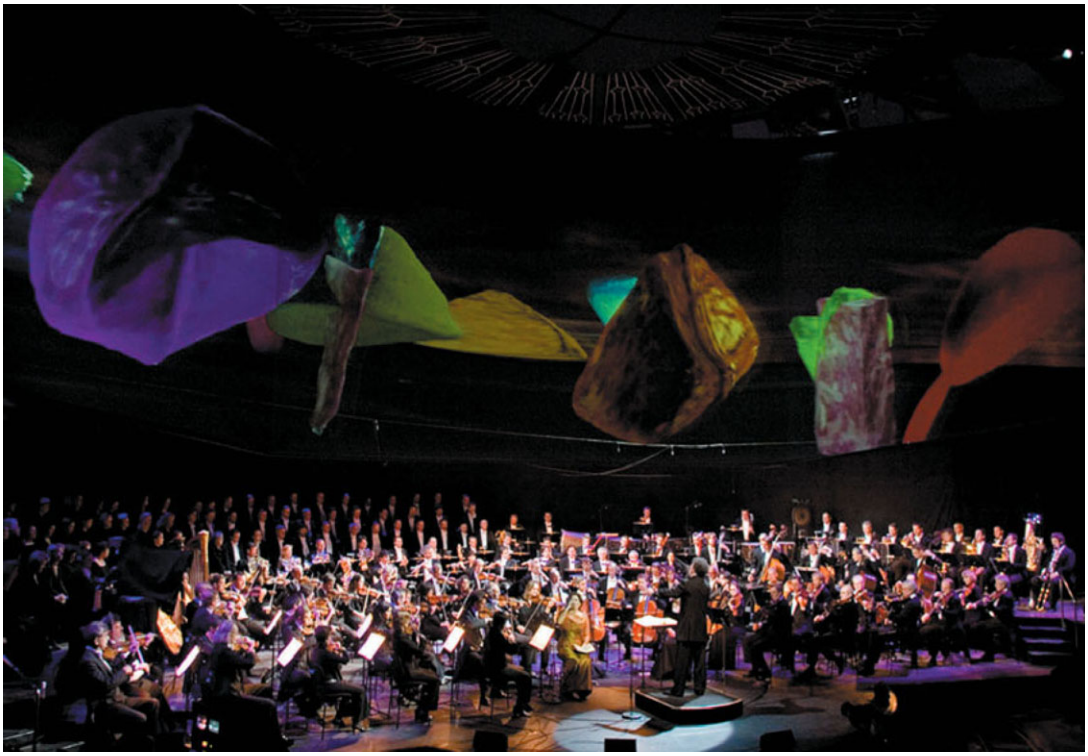

Fig. 3 Gustav Mahler "Symphony No. 2 in C minor", V. Movement, Concert performance at Philharmonic Concert Hall of Cologne, 2006

ence involving several senses simultaneously can be evoked in the audience.

In the following the author's path to the visualization is described in some detail from both the aesthetic and the technical point of view.

First, the Symphony had to be analyzed and interpreted. Inspired by Mahler's music, a total of eighteen three dimensional objects were developed to provide the basis of the 3-D visualization. The design of the visual images was based on the statements made in the music and the emotions released by it. Two interpretations had to be blended: one expressed musically and the other visually. In the given case the cultural-historical ambience of Gustav Mahler and his own sources of inspiration were not the subject of the visualization.

In order to understand how the authors's visualizations have been able to reach his audience, it is helpful to mention Haverkamp's commentary on the visualization of the author. Haverkamp (2010, p. 2) argues that indeed "an incalculable number of visualizations of music can be generated on the basis of computerized analysis of sound. Algorithms generate visual elements, whose features are – partly or as a whole – correlated to selected parameters of the music." But they simply fail to become an art work. Consequently, Haverkamp raises the question how the artist has been able to create not merely an "entertaining" but an "œuvre d'art". Apart from the already outlined steps which Haverkamp (2010, p. 2) termed the intentional "conscious concepts" of the artist, he also described at least three main steps of "intuitive coupling" which together enable the artist to reach the audience. All three steps are influenced by the context of perception (thus differing from genuine

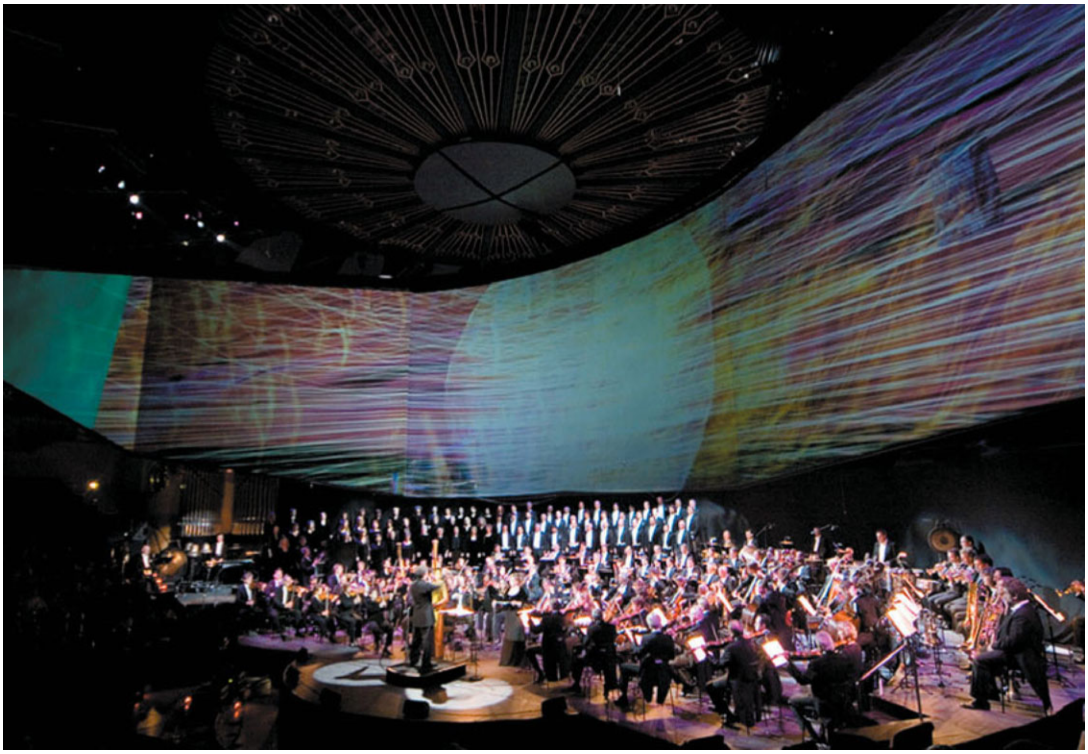

Fig. 4 Gustav Mahler "Symphony No. 2 in C minor", V. Movement, Concert performance at Philharmonic Concert Hall of Cologne, 2006

synaesthesia): (i) Intermodal or cross sensory analogies, including correlations of single attributes (e. g., generic attributes such as intensity, brightness, sharpness etc.; motion; synchronicity). The concept of "intermodal analogy" was introduced by Robert Melara, an experimental psychologist, who investigated the dimensional interactions between color and pitch experimentally (Melara 1989a, b). (ii) Iconic coupling is based on a concrete association referring to known physical object, meaning the identification of sources of stimuli. Iconic coupling refers to objects in memory and is based on learning and experience (e. g., the sound of crackling refers to the image of fire). (iii) Symbolic connections implying semantic correlations (meanings of the auditory and visual symbols as well as meanings of their connections) (Haverkamp 2010).

On an abstract level eighteen 3-D objects represent the world of the Second Symphony as a kind of virtual domain. Like the music, the objects of the visualization undergo a transformation that Mahler brings to us as a musical experience across five movements. The specific thematic junctures and stages of the five movements of the symphony – suffering, romance, irony, love, doubt, and hope – are associated with the transformation of these virtual objects. As Haverkamp (2010, p. 5) remarks commenting on the visualization of the author: "The animation refers to the composition by means of a color concept which supports narrative aspects of the music. Without losing their abstract appearance, the visual elements correlate to the thematic stages of this Symphony [. . .]". For example, the transformations occur in the first movement when the objects rise up and then

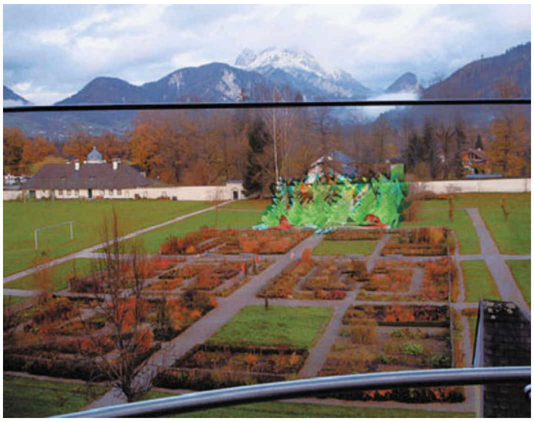

Fig. 5 "The invisible garden", location of the garden, draft 2006

break down, or in the second movement when they dance, radiate, and shine. In the third movement, irony influences the shapes and causes them to be distorted, while love causes them to glow in the fourth movement, whereas in the fifth movement follow tremors, earthquake, and destruction, with the objects bursting and triggering an exodus in the virtual world. Redemption does not come until the very end when everything shimmers, sails, and soars.

Regarding the spatial shapes created by the author, Haverkamp remarked: "Eighteen elementary forms carry the colors and are subject of various form transformations and groupings in space. Those forms were constructed physically and have been scanned into the virtual environment. The whole scenery, however, remains abstract. The only exception is given during the 4 th movement ("Urlicht" ["Primary or early light"]) where an iconic ambience of romanticism reminds to how the moon appears above a nightly landscape, roughly comparable to surreal sceneries unfolded by the painter Max Ernst." (Haverkamp 2010, pp. 5–6)

What is different in the author's visualisation of Mahler's "Symphony No. 2 in C minor" with respect to other current animations? According to Haverkamp, in "contrast to being a predetermined sequence of animation, the presentation is interactive in nature. Sounds of musical instruments directly influence the scenery by initiating synchronous light effects, object pulsation, and movement. For that purpose, sensors were attached to a variety of instruments throughout the orchestra." (Haverkamp 2010, p. 6)

As the objects evolve through the stages of the symphony, a pulsing becomes visible on their surfaces as if their hearts were beating or their lungs breathing. The degree to which the objects pulsate, as well as how and even whether their radiance visibly manifests itself, depends upon the music and its interpretation during the actual performance. The vision is real-time and interactively linked to the music, enlivening the virtual objects like a pace-maker. In this way, the visualization reflects the extreme contrasts of the dramatic and lyrical movements, ranging from playful to religious; from powerful expressions of release and joy through to profound emotional turbulence.

The objects' movements are a key element of the author's visualization, because they enhance the movements of the music by visualizing them. In order to understand why movement is so crucial for communicating music in performance and thus for really reaching the audience let me refer again to Haverkamp. In a previous paper by Haverkamp (2007) the analogy between music and motion is shown acting according to the rule that "motion is the primal element of music," a statement expressed by the recently rediscovered German musicologist Alexander Truslit in his "Gestaltung und Bewegung in der Musik" ["Shaping and motion in music"] (Truslit 1938). Truslit provided a pioneering theory of the basis of common music experience of the audience, a theory of "musical" listening of the audience – as distinct from the "musicological" listening of expert musicologists (Cook 1990) –, studying subjects' responses to music as well as their inner physiological motion (Repp

Fig. 6 "The invisible garden", leafs, summer 2010. The garden has been conceived on the model of interaction with and immersion in a virtual world and so only is apparent after specific navigation. This special garden borders on the herb garden. It is visually and hermetically sealed from the outside by a thicket-like hedge of pines. Within it, the non-visual senses (touching, smelling, hearing etc.) are exposed – on a predetermined path – to various young trees from the region which have been chosen and planted on haptic, olfactory, and acoustic criteria. Our hands (as also our hearing and our smelling) become "data gloves" and navigators through this immersion in the natural and yet unusual world of perception.
Our visually impaired museum and art guides are more experienced in navigating this difficult thicket. By exchanging experiences they help us to come to grips with this world. They also arouse our attention in an extension of our normal awareness for the specific plastic, tactile, olfactory, and acoustic qualities of the museum garden (Deutsch 2010, 2011)

1992). Truslit's assumption of the transmission of motion information from the musicians to the audience can be compared to the theory of Liberman and Mattingly for speech perception (Liberman and Mattingly 1985; cf. Repp 1992). According to Truslit, music is a biologically conditioned form of motion shaped by its inner movement. Indeed, just by means of its inner movement music enables the listener to experience what music brings to sound. Truslit assumed a close relationship between the hearing organ, the vestibular organ, and the body muscles: the auditory sensations are paired with an inner motion experience and corresponding muscular reactions (Haverkamp 2007). Truslit's proposal that the vestibulum is the organ of music motion is supported by contemporary researchers in acoustics such as Todd (1992). In general, Truslit's biological hypothesis can be compared to the neuropsychological approach of Clynes (1986; Clynes and Nettheim 1982).

The ability of the 3-D objects to change makes it possible to capture the distinctive symphonic quality of the Second Symphony. While Gustav Mahler's tonal settings are generally well known for their ideal synthesis of word and sound, the aspect that fascinates the media artist most about the Symphony is the direct translation of meaning into music. The sequential order of the music allows Mahler's statements to be understood, in a sense, word for word, and the series of emotions generated by the music thus evoke a kind of mental filmstrip. Based on this inherent potential, the 3-D space in the Philharmonic Hall was used as a visually immersive counterpoint encompassing all the senses, while radiance and darkness, majesty and turbulence pass over and through all the objects.

3.1 The technology

A complex computer cluster, designed together with the Ars Electronica Futurelab of Linz, was used to generate the real-time visualization of Mahler's Symphony No. 2. The cluster simultaneously processed and implemented any modulations picked up from the orchestra. Its 56 musical instruments were fitted with microphones and individual soundtracks and linked by sensors directly to the computer cluster providing all the nuances of the live interpretation of the music before translating these directly into variable visual elements.

The computer systems generated a virtual world in real time resulting from the synthesis of music and vision, which meant that the performers (under the direction of conductor Semyon Bychkov) interactively shaped the visual dramaturgy with their own interpretation. They could indeed influence the appearance of the objects, their movement, and their intensity of movement. The audience inside the Philharmonic Concert Hall – equipped with 3-D glasses – entered an all-embracing virtual world projected onto a curved panoramic screen. It thus had the opportunity to perceive the musical and the visual simultaneously and to see how the musician's own interpretation was visualized.

Additionally, the computing system simultaneously generated a variant of the virtual world for the live television feed using dramaturgically-driven virtual cameras. These cameras, also developed at Futurelab, opened up the digitally-designed virtual world to the television viewer by moving independently through the artificial environment according to choreographed criteria. In addition to the real cameras located in the Philharmonic Concert Hall, this gave the television production an innovative and cinematic dimension that in terms of content was closely linked to the music.

Information systems computed when, where, and from what perspective the interactive fusion of music and vision could best be achieved. In this way, a TV variation of the visualization could be broadcast live.

The computer also supplied clips of the projection adapted to the 16:9 TV format, giving them an exceptional depth. With the help of 3-D glasses this effect was further enhanced.

The special achievement of the WDR production was to assemble all three visual levels – the real visual level in the Philharmonic Concert Hall in Cologne, the virtual camera tracking shots, and the clip level. This meant that the television audience had the opportunity to visualize the Symphony from several different angles.[2]

[2] At the director's console, the four direct TV feeds of the visualization were mixed live with images captured by TV cameras set up in the Philharmonic Concert Hall to provide an exceptional multi-layered visual experience. This particular visual experience has been published as the first DVD "Vision Mahler. Artist's edition – Johannes Deutsch 1" (2006b).

Conclusion

Has cross sensory coupling to be considered as a common type of neuronal processing in both synaesthetes and average population? Are intermodal associations immediately available to consciousness for synaesthetes only? The answer is: possibly yes. Another question is: Do the results of scientific research provide evidence that non-synaesthetes show fixed patterns of coupled association as well? Some data seems to corroborate this assumption. Simner and colleagues showed that in grapheme-colors synaesthesia both synaesthetes and non-synaesthetes prefer certain pairings of letters and colors: "A" to red, "S" to yellow, "X" to black (Simner et al. 2005). According to recent studies synaesthetes tend to see lighter colors when exposed to increasingly higher frequency sounds and the same pairing between luminance and pitch was found in average people making intuitive music-color associations (Ward et al. 2006).

In art, cross sensory coupling seems not only to be a common form of processing sensory information, but something that artists intentionally employ as a tool. A key-question then obviously refers to the involuntary, automatic coupling. Do artists show fixed patterns of paired associations? Rimski-Korsakov employed F frequently for his pastoral music, because it recalls green leaves and grass, maintaining that his own associations rooted in his biography. For Kandinsky yellow was the colour of middle-C on a piano (Kandinsky 1994). On the other side, Baudelaire pleaded for the intentionality as well as the variability of the correspondences in poetry and art. Rimbaud explicitly strengthened this program in his literary work. In music, Rimington constructed mathematical-physical correlations coupling C, the lowest-pitched tone, with red, the color resulting from the lowest frequency (longest wavelength) light (Rimington 1911). Finally, Hermann Nitsch also strongly assumed intentional construction in visual art. Does the complex aesthetic and technical conception of contemporary art, especially of interactive media art, not provide evidence enough that art has little to do with involuntariness?

Knowing that genuine and spontaneous synaesthesia is far more common than previously assumed does not help to simply link the involuntary neurological condition to the production of art. However, on the other side, it could allow the formulation of a tentative hypothesis about the experience of the audience.

References

Anschütz G (1925) Untersuchungen zur Analyse musikalischer Photismen. Arch Gesamte Psychol 51: 155–218

Anschütz G (1926) Untersuchungen über komplexe musikalische Synopsie. Arch Gesamte Psychol 54: 129–273

Anschütz G (ed) (1927) Farbe-Ton-Forschungen. vol 1. Akad Verlagsges, Leipzig

Anschütz G (ed) (1931) Farbe-Ton-Forschungen. vol 3. Bericht über den 2. Kongress für Farbe-Ton-Forschung. Verlag der Psychologisch-ästhetischen Forschungsges, Hamburg

Anschütz G (ed) (1936) Farbe-Ton-Forschungen. vol 2. Verlag der Psychologisch-ästhetischen Forschungsges, Hamburg [published after vol 3]

Asher J E, Aitken M R F, Farooqi N, Kurmani S, Baron-Cohen S (2006) Diagnosing and phenotyping visual synaesthesia: a preliminary evaluation of the revised Test of Genuineness (TOG-R). Cortex 42: 137–146

Asher J E, Lamb J A, Brocklebank D, Cazier J B, Maestrini E, Addis I, Mallika S, Baron-Cohen S, Monaco A P (2009) A whole–genome scan and fine-mapping linkage study of auditory-visual synaesthesia reveals evidence of linkage to chromosomes 2q24, 5q33, 6p12 and 12p12. Am J Human Genet 84: 279–285

Aristotle (1936) On sense and sensible objects. In: Goold GP (ed) Aristotle in twenty-three volumes, vol 8. Harvard Univ Press, Cambridge MA, pp. 205–283

Baker J M (1986) The music of Alexander Scriabin. Yale Univ Press, New Haven, London

Baratoux J (1888) De l'audition colorée. Chaix, Paris

Barnett K J, Newell F N (2008) Synaesthesia is associated with enhanced, self-rated visual imagery. Conscious Cogn 17: 1032–1039

Baron-Cohen S (1994) Synaesthesia: an account of colored hearing. Leonardo 27: 343–346

Baron-Cohen S, Burt L, Smith-Laittan F, Harrison J, Bolton P (1996) Synaesthesia: prevalence and familiarity. Perception 25: 1073–1079

Baron-Cohen S, Harrison J (eds) (1997) Synaesthesia: classic and contemporary readings. Blackwell Publishers, Cambridge MA

Baron-Cohen S, Harrison J, Goldstein L H, Wyke M A (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 colors: an experimental investigation of a case of synaesthesia. Perception 16: 761–767

Baudelaire C (1993 [1857]) The flowers of evil. Translated by McGowan J and with an introd by Culler J. Oxford Univ Press, Oxford, New York

Beaunis H, Binet A (1892) Sur deux cas d'audition colorée. Rev Philos 33: 448–461

Behne K – E (ed) (1987) Film-Musik-Video oder Die Konkurrenz von Auge und Ohr. Gustav Bosse Verlag, Regensburg

Bidaine P (ed) (2004) Sons & Lumières. Une histoire du son dans l´art du XXe siècle. Éditions du Centre Pompidou, Paris

Binder T (2004) Auf Entdeckungsreise: „Das Rheingold" als virtuelle, dreidimensionale Götterwelt. Interview mit Johannes Deutsch. In: Das Rheingold. Oper visualisiert. Programmheft Brucknerfest Linz 2004. Publisher Brücknerhaus, Linz, pp 4–8

Binet A (1892) Le problème de l'audition colorée. Rev Deux Mondes 63: 586–607

Binet A, Philippe J (1892) Étude sur un nouveau cas d'audition colorée. Rev Philos 33: 461–464

Bleuler E (1913) Zur Theorie der Sekundärempfindungen. Z Psychol 65: 321–401

Bleuler E, Lehman K (1881) Zwangsmäßige Lichtempfindungen durch Schall. Fues's Verlag, Leipzig

Bos M C (1929) Über echte und unechte audition colorée. Z Psychol 111: 321–401

Castel L B (1725) Clavecin pour les yeux. Mercure de France. November: 2552–2577

Castel L B (1726 a) Démonstration géométrique du clavecin pour les yeux et pour tous les sens. Mercure de France. February: 277–292

Castel L B (1726 b) Difficultés sur le clavecin oculaire, avec leurs réponses. Mercure de France. March: 455–465

Castel L B (1751) Du clavecin oculaire. Mercure de France. Dec: 7–21

Chabalier C (1864) De la pseudochromesthésie. J Méd Lyon 2: 92–102

Claparède E (1900) Sur l'audition colorée. Rev Philos 49: 515–521

Clavière J (1898) L'audition colorée. Année Psychol 5: 161–178

Clynes M (1986) Music beyond the score. Communication and Cognition 19: 169–194

Clynes M, Nettheim N (1982) The living quality of music: neurobiological patterns of communicating feeling. In: Clynes M (ed) Music, mind, and brain. Plenum Press, New York, pp 47–82

Cook N (1990) Music, imagination, and culture. Clarendon Press, Oxford

Cornaz E (1851) De l'hyperchromatopsie. Ann Ocul (Paris) 25: 3–9

Cortex (2006) Cognitive neuroscience perspectives on synaesthesia (special issue) 42/2

Cortex (2009) Synaesthesia and visuo-spatial forms (special section) 45/10: 1190–1277

Cytowic R E (1989) Synaesthesia: a union of the senses. 1st edn. Springer, New York

Cytowic R E (2002) Synaesthesia: a union of the senses. 2nd edn. MIT Press, Cambridge, MA

Cytowic R E, Eagleman D M (2009) Wednesday is indigo blue: discovering the brain of synaesthesia. MIT Press, Cambridge, MA

Daubresse M (1900) L'audition colorée. Rev Philos 49: 300–306

Day S A (2007) Demographic data http://home comecast.net/-sean.day

Deutsch J (2002) Gesichtsraum – CAVE. In: Unplugged – Art as the scene of global conflicts. Ars Electronica 2002. Hatje Cantz Verlag, Ostfildern-Ruit, p 347

Deutsch J (2004) Das Rheingold – virtual realm of the gods. In: Timeshift – the world in twenty-five years. Ars Electronica 2004. Hatje Cantz Verlag, Ostfildern-Ruit, pp 219–221

Deutsch J (2006 a) Das Rheingold – virtuelle Götterwelt. In: Louis E, Stoos T (eds) Kunst auf der Bühne – Art on stage. Les grands spectacles II. Publisher Museum der Moderne Salzburg, Salzburg, pp 144–146

Deutsch J (2006 b) Vision Mahler. Artist's edition – Johannes Deutsch 1. DVD. Art Haus Musik, Leipzig, Berlin

Deutsch J (2006 c) Vision Mahler. In: Simplicity – the art of complexity. Ars Electronica 2006. Hatje Cantz Verlag, Ostfildern-Ruit, pp 296–299

Deutsch J (2007) Vision Mahler. Artist's edition – Johannes Deutsch 2. DVD. Art Haus Musik, Leipzig, Berlin

Deutsch J (2008) Vision Mahler, interactive visualization. In: Migrating reality. Publisher KHM Kunsthochschule für Medien, Köln, Berlin, Vilnius, pp 54–60

Deutsch J (2010) Der unsichtbare Garten 2007. In: Braunsteiner M, Peters C (eds) Play Admont. Stift Admont. Bibliothek der Provinz, Weitra, pp 22–23

Deutsch J (2011) www. johannes-deutsch. at
Dixon M J, Smilek D, Merikle P M (2004) Not all synaesthetes are created equal: projector versus associator synaesthetes. Cogn Affect Behav Neurosci 4: 335–343
Dixon M J, Smilek D (2005) The importance of individual difference in grapheme-color synaesthesia. Neuron 45: 821–823
Dixon M J, Smilek D, Duffy P L, Zanna M P, Merikle P M (2006) The role of meaning in in grapheme-color synaesthesia. Cortex 42: 243–252
Düchting H (1996). Farbe am Bauhaus. Synthese und Synästhesie. Neue Bauhausbücher. Gebrüder Mann, Berlin
Eagleman D M, Kagan A D, Nelson S S, Sagaram D, Sarma A K (2007) A standardized test battery for the study of synaesthesia. J Neurosci Methods 159: 139–145
Emrich H M, Schneider U, Zedler M (eds) (2002) Welche Farbe hat der Montag? Synästhesie: das Leben mit verknüpften Sinnen. S. Hirzel Verlag, Stuttgart, Leipzig
Fechner G T (1898) Vorschule der Ästhetik. 2 vol. (2nd edn) Breitkopf and Härtel, Leipzig
Field G (1835) Chromatography; or, a treatise on colours and pigments and of their powers in painting. Charles Tilt, London
Fischer E (ed) (2008) Sound: Frame, Festival zur Visualisierung elektronischer Musik. Czernin Verlag, Wien
Flournoy T (1892) Enquête sur l'audition colorée. Extrait des archives des sciences physiques et naturelles, troisième période, Genève 28
Flournoy T (1893) Des phénomènes de synopsie. Alcan, Paris and Charles Eggimann & Cie, Genève
Frith C D (2001) Brain imaging psychological disorders. In: Underwood G (ed) The Oxford guide to the mind. Oxford Univ Press, Oxford, pp 154–159
Galton F (1880a) Visualised numerals. Nature 21: 494–495
Galton F (1880b) Visualised numerals. J R Anthropol Instit 10: 85–102
Galton F (1880c) Statistics on mental imagery. Mind 5: 301–318
Galton F (1883) Inquiries into human faculty and its development. E P Dutton, New York
Grossenbacher P G, Lovelace C T (2001) Mechanisms of synaesthesia: cognitive and physiological constraints. Trends Cogn Sci 5: 36–41
Gruber E (1893) Questionnaire psychologique sur l'audition colorée, figurée et illuminée. Rev Philos 35: 499–502
Hay D R (1836) The laws of harmonious colouring, adapted to interior decorations, manufactures, and other useful purposes. 3rd edn. W & R Chambers, Edinburgh
Haverkamp M (2007) Bewegung als Ursprung der Musik. Alexander Truslits frühe Studien zur Musikwahrnehmung. In: Forschritte der Akustik. Plenarvorträge und Fachbeiträge der 33. Deutschen Jahrestagung für Akustik DEGA. Publisher Dtsch Ges f Akustik DEGA, pp 557–558
Haverkamp M (2009a) Synästhetisches Design, kreative Produktentwicklung für alle Sinne. Hanser Verlag, München
Haverkamp M (2009b) Look at that sound! Visual aspects of auditory perception. Paper at the 3rd Congreso intyernacional de sinestesia, cienncia y arte, Grenada
Haverkamp M (2010) Visualizing auditory perception: correlations, concepts, synaesthesia. Paper at the Galayev readings 2.–5. 10. 2010, Prometheus-Institute, Kazan, Russia
Henri V (1893) Notes sur un cas d'audition colorée. Rev Philos 35: 554–558
Hupé J-M (2010) Psychophysics and fMRI of grapheme-color synaesthesia. Paper at the UKSA [United Kingdom Synaesthesia Association] Congress, March 2010, University of Sussex, Brighton
Hupé J-M, Bordier C, Dojat M (2010) Colors in the brain and synaesthesia. Abstract. Paper at the 33th ECVP [European Conference on Visual Perception] August 2010, Lausanne, Switzerland. Perception 39 (Supplement): 159
Hubbard E M, Ramachandran V S (2005) Neurocognitive mechanisms of synaesthesia. Neuron 48: 509–520
Jewanski J (1997) Die Farblichtmusik Alexander Lászlós. Z Kunstgesch 1: 12–43
Jewanski J (1999) Ist C = Rot? Eine Kultur- und Wissenschaftsgeschichte zum Problem der wechselseitigen Beziehung zwischen Ton und Farbe: von Aristoteles bis Goethe. Berliner Musik Studien 17. Studio Schewe Verlag, Sinzig
Johnson B D (1975) Messiaen. Univ California Press, Berkeley, Los Angeles
Kandinsky W (2001 [1911]) Concerning the spiritual in art. In: Glew A (ed) MFA Publications, Tate Publishing, London New York
Kandinsky W (1994) Complete writings on art. In: Lindsay K C, Vergo P (eds) Da Capo Press, Cambridge, MA

László A (1925) Die Farbenlichtmusik. Breitkopf & Härtel, Leipzig

Lauret J, Duchaussoy L (1887) Un cas héréditaire d'audition colorée. Rev Philos 23: 222–224

Lemaitre A (1904) Un cas d'audition colorée hallucinatoire. Arch Psychol (Genève) 3: 164–177

Lemke H (2006) Das Manifest der futuristischen Koch-Kunst. Annäherungen an die Eat Art. In: recenseo, Texte zu Kunst und Philosophie, Saarbrücken http://www. recenseo. de/index. php?id =91&kategorie=artikel&nav=Inhalt

Liberman A M, Mattingly I G (1985) The motor theory of speech revisited. Cognition 21: 1–36

Ligeti G (1958) Artikulation. Electronic composition. Hörpartitur by Wehinger R (1970). Schott's Söhne, Mainz

Ligeti G (1983) Ligeti in conversation. Eulenburg Books, London

Maresch P (2010) Conversation with Johannes Deutsch on 16 th January 2003. In: Hattinger G, Bogner P (eds) Space inventions. Der künstliche Raum. Schlebrügge, Wien, pp 128–131

Marinetti F T (1989 [1932]) The futurist cookbook. Trans by Brill S and with an intr by Chamberlein L. Bedford Art Publisher, San Francisco

Marinetti F T, Fillia L E C (1930) Manifesto della cucina futurista [Manifesto of the futurist cuisine]. Gazzetta del Popolo, Torino, 28. 12. 1930

Melara R D (1989a) Dimensional interaction between color and pitch. J Exp Psychol Hum Percept Perform 15/1: 69–79

Melara R D (1989b) Dimensional interaction between color and pitch. J Exp Psychol Hum Percept Perform 15/2: 212–231

Messiaen O (1948) L'ascension: quatre méditations symphoniques pour orchestre. Alphonse Leduc, Paris

Metzger J (2010) Synästhesie: Ich sehe etwas, was du nicht siehst. Psychologie heute 37: 44–49

Moritz W (1987) Der Traum von der Farbmusik. In: Bódy V, Weibel P (eds) Clip, Klapp, Bum. Von der visuellen Musik zum Musikvideo. DuMont Verlag, Köln, pp 17–51

Moritz W (1997) The dream of color music, and machines that made it possible. Animation World Magazine 2/1 April 1997 [Internet Journal]

Moritz W (2006) Der Traum, Musik sichtbar zu machen. In: Vision Mahler. Programmheft zum Festkonzert zum 50-Jahr Jubiläum des Westdeutschen Rundfunk WDR, Köln, pp 28–29

Newton I (1704) Opticks or a treatise of the reflections, refractions, inflections and colours of light. Smith and Walford Printers to the Royal Society, London

Nichols R (1896) Olivier Messiaen. 2nd edn. Oxford University Press, Oxford, New York

Nitsch H (1995) Vom Orgien Mysterien Theater zur Operninszenierung. In: Massenet – Hérodiade. Programmheft der Wiener Staatsoper, Wien

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 synaesthesia: activation of V4/V8 by spoken words. Nat Neurosci 5: 371–375

Peacock K (1988) Instruments to perform color-music: two centuries of technological experimentation. Leonardo 21: 397–406

Pelzmann B (2008) Vision Mahler – Bilder einer Sinfonie. EIKON Internat Z Photographie & Medienkunst 61: 71–73

Pfister O (1912) Die Ursache der Farbenbegleitung bei akustischer Wahrnehmungen und das Wesen anderer Synästhesien. Imago 1: 265–275

Philippe J (1893) Résumée d'une observation d'audition colorée. Rev Philos 36: 330–334

Prampolini E (1913) Gazzetta Ferrarese, 26th August 1913, Ferrara, Italy

Ramachandran V S, Hubbard E M (2001a) Psychophysical investigations into the neural basis of synaesthesia. Proc R Soc Lond B Biol Sci 268: 979–983

Ramachandran V S, Hubbard E M (2001b) Synaesthesia: a window into perception, thought and language. JCS 8: 3–34

Repp B H (1992) Music as motion: a synopsis of Alexander Truslit's (1938) „Gestaltung und Bewegung in der Musik". Haskins Laboratories Status Report on Speech Research 111/112: 265–278

Riccò D (1999) Sinestesie per il design. Le interazioni sensoriali nell'epoca dei multimedia. Etas, Milano

Riccò D (2008) Sentire il design. Carrocci, Roma

Rimbaud A (2001 [1871]) Vowels. In: Sorrell M (ed) Arthur Rimbaud. Collected Poems. Transl, with an introd and notes by Sorrell M. Oxford University Press: Oxford, New York, pp 134–135

Rimbaud A (2001 [1873]) Alchemy of the word. In Sorrell M (ed) Arthur Rimbaud. Collected Poems. Translated, with an introd and notes by Sorrell M. Oxford Univ Press, Oxford, New York, pp 234–237

Rimington, A W (1911) Color-music. The art of mobile color. Hutchison & Co, London

Samuel C (1994) Olivier Messiaen: music and color. Conversations with Claude Samuel. 2nd edn. Amadeus Press, Portland, Oregon

Scheel S (2006) Music visualization – the interplay of color and sound. In: Simplicity – the art of complexity. Ars Electronica 2006. Hatje Cantz Verlag, Ostfildern-Ruit, pp 273–289

Shakespeare W (1926 [1594–96]) A midsummer night's dream. In: Quiller-Couch A, Wilson J D (eds) The works of Shakespeare. Cambridge Univ Press, Cambridge

Scriabin A (1995 [1911]) Poem of ecstasy. Prometheus: poem of fire. Dover, New York

Scriabin A (1911) Prometheus. Poem of fire. At the Tonhalle Düsseldorf: http://www. youtube. com/ watch?v=9CruEBhdxJE

Simner J (2006) Beyond perception: synaesthesia as a psycholinguistic phenomenon. Trends Cogn Sci 11: 23–29

Simner J (2009) Synaesthetic visuo-spatial forms: viewing sequence in space. Cortex 45: 1138–1147

Simner J, Ward J, Lanz M, Jansari A, Noonan K, Glover L, Oakley D A (2005) Non-random associations of graphemes to colors in synaesthetic and non-synaesthetic populations. Cogn Neuropsychol 22: 1069–1085

Simner J, Ward J (2006) The taste of words on the tip of the tongue. Nature 444: 438

Simner J, Harold J, Creed H, Monro L, Foulkes L (2009) Early detection of markers for synaesthesia in childhood populations. Brain 132: 57–64

Sokolov P (1901) L'individuation colorée. Rev Philos 51: 36–46

Suarez de Mendoza F (1890) L'audition colorée. Octave Doin, Paris

Todd N P (1992) The dynamic of dynamics: a model of musical expression. J Acoustic Soc Am 91: 3540–3550

Topper D (1999) Newton and the number of colors in the spectrum. Stud Hist Philos Sci 21: 269–279

Trenks B (2005) 4.5 Johannes Deutsch. Exemplarische Analyse der Lichtgestaltung eines Bühnenwerkes (Richard Wagners „Das Rheingold"). In: Inszeniertes Licht im Bühnenraum. Diplomarbeit. Akademie der Bildenden Künste, Wien, pp 78–86

Truslit A (1938) Gestaltung und Bewegung in der Musik. C F Vieweg Verlag, Munich

Ulrich A (1903) Phénomènes de synesthésies chez un épileptique. Rev Philos 56: 181–187

von Hug-Hellmuth H (1912) Über Farbenhören. Imago 1: 228–264

von Leliwa E (2010) Theater im Kopf. Interview mit Regisseur Johannes Deutsch. In: Robert Schumann. Manfred. Programmheft der Tonhalle Düsseldorf, Düsseldorf, pp 4–17

Walz S B (2008) 4. Das Rheingold. In: Mediale Analogien von Musik und Bild. Theatrale Abstraktionen in Musikinszenierungen. Diplomarbeit. Ludwig-Maximilians-Univ, München, pp 60–78

Ward J, Huckstep B, Tsakanikos E (2006) Sound-color synaesthesia: to what extent does it use cross-modal mechanisms common to us all? Cortex 42: 264- 280

Weibel P (1987) Von der visuellen Musik zum Musikvideo. In: Bódy V, Weibel P (eds) Clip, Klapp, Bum. Von der visuellen Musik zum Musikvideo. DuMont, Köln, pp 53–163

Wellek A (1927) Die Farbe-Ton-Forschung und ihr erster Kongress. Z Mw 9: 576–584

Wellek A (1931 a) Zur Geschichte und Kritik der Synästhesie-Forschung. Arch Gesamte Psychol 79: 325–384

Wellek A (1931 b) Zur Entwicklung unserer Notenschrift aus der Synopsie. In: Anschütz G (ed) Farbe-Ton-Forschungen. vol 3. Bericht über den 2. Kongress für Farbe-Ton-Forschung. Verlag der Psychologisch-ästhetischen Forschungsgesellschaft, Hamburg, pp 143–153

Winkler W (2005) Visualized music – an old theme, a new theme. In: Hybrid – living in paradox. Ars Electronica 2005. Hatje Cantz Verlag, Ostfildern-Ruit, pp 325–328

Winkler W (2006) The visualization of music. In: Simplicity – the art of complexity. Ars Electronica 2006. Hatje Cantz Verlag, Ostfildern-Ruit, pp 300–301

Zuckriegl M (2010) An image of space. In: Hattinger G, Bogner P (eds) Space inventions. Der künstliche Raum. Schlebrügge, Wien, pp 132–139