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Synaesthesia: How can it be used to enhance the audio-visual perception of music and multisensory design in digitally enhanced environments?

Svetlana Rudenko[1], *João P. Cabral*[2]

[1] Bray Institute of Further Education, Ireland
[2] Trinity College Dublin, Ireland
rudenkos@tcd.ie, cabralj@scss.tcd.ie

Abstract

Synaesthesia is a type of sensory cross-activation related to a specific wiring of the brain which has additional neuronal pathways between different cortexes, creating various sensory experiences, such as people "hearing colours" or "seeing sounds". There is a great potential of applying the knowledge about synaesthesia in different fields. For example, it could lead to innovative developments of educational programs for the young age cross-modal perception, digital applications for children with autism, and technological solutions to train plasticity of ageing brain. Synaesthetes very often benefit from their condition, especially in production of creative works, transposing experience from one sensory modality to another. For example, mixing sounds to create colour palette, as Vincent van Gogh, or composing modes of limited transposition with very clear view of colours, as Olivier Messiaen. Both had the chromaesthesia type of synaesthesia. This paper reviews important achievements in modelling synaesthetes perceptual experiences, with a focus on audio-visual perceptions, such as 4D digital visualisation of musical texture/musical-space synaesthesia, Cognitive Musicology visuals for classical music based on cross-modal associations and composing for animated Art. We also discuss the implications of the cross-modal sensory output on visual digital applications. Our assumption is that applications of cross-modal perception models based on synaesthesia can contribute to more engaging experiences to users, including the possibility to stimulate plasticity of the brain through multisensory design and digitally enhanced environments in Augmented Reality (AR) and Virtual Reality (VR).

Index Terms: Art and Music Education, Cross-Modal Perception, Synaesthesia, Brain Plasticity, Healthy Ageing, Artificial Intelligence, Cognitive Musicology, Multisensory design

1. Introduction

Synaesthesia is a benign condition that is characterised by cross-modal perceptions - in addition to perceiving one stimulus, people with synaesthesia may perceive an additional quality to the experience – a colour or smell or feeling. The brain of a new-born baby is cross-modal and experiences infants synaesthesia, "the senses are intermingled, in which vision may be triggered by hearing as well as sight, and so on" [1]. Further into adulthood, nature prevents the brain from sensory overload by separating senses into logical functionality.

Music is one of the stimuli that can induce cross-modal perception. Composers and visual artists alike have tried to capture these synaesthetic experiences - either mapping general cross-sensory correspondences that are common across the population (such as linking higher pitched notes with brighter colours) or attempting to convey the much more idiosyncratic subjective experiences through multimodal performances or visual art. As V.S. Ramachandran and E.M. Hubbard point out [2]: "just as synaesthesia involves making arbitrary links between seemingly unrelated perceptual entities such as colors and numbers, metaphor involves making links between seemingly unrelated conceptual realms", which could lead to creativity [3]. A very interesting characteristic of synaesthesia is that the multi-sensory connection is naturally generated as the result of the neurological activity. Thus, it is expected that the modalities are synchrnoised and link well together. For example, this is supported by the often encountered positive reactions of acceptance and admiration by people to the art creations of synaesthets. Jamie Ward, Professor at Sussex University, author of the book "The Frog Who Croaked Blue" [1], conducted an experiment in which 200 random visitors at the Science Museum in London were asked to view two musical animations. In the article of Discover magazine Garfield[1] he described: "One [animation] was designed by synaesthetes to accompany a piece of music; the other was designed by non synaesthetes. When asked, which animation better matched the music, volunteers overwhelmingly chose the **synaesthete-designed animation**, indicating that even though they did not realize it, their brains were closely attuned to the synchronisation of different senses.".

In the following parts of the introduction, we explain synaesthesia from the point of view of multi-sensory perception and its relation to transposition of sensory experiences through examples of real-life situations or applications. Section 2 presents a summary of the study about synaesthesia related to art on music, which was carried out by the first of author of this paper through interviews to a number of artists. Section 3 gives an overview of different projects carried out by the authors that explore synaesthesia to produce engaging audio-visual experiences. Next, Section 4 briefly describes a number of emerging applications of synaesthesia that are in line with our future work. Finally, the concluding remarks are given in Section 5.

1.1. Synaesthesia as a window to Multisensory Perception

According to the Oxford dictionary[2], the definition of 'Multisensory' is 'involving or using more than one of the senses'. There is a clear link between synaesthesia and multisensory perception, but the multisensory effect can also be experienced by a broader population. For instance, A. Rieger and M. Casey wrote: "Köhler was the first to describe the linguistic 'Kiki, Bouba Effect' which revealed a sound-to-pictorial/shape association among general (non-synaesthetic) subjects. In more recent replication studies of the Kiki-Bouba experiment, over 90 percent of all subjects identified the spiked shape with the

[1] http://discovermagazine.com/2006/dec/synesthesia-appears-ubiquitous

[2] https://en.oxforddictionaries.com/definition/multisensory

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name Kiki, and the rounder shape as Bouba. These experiments support the hypothesis that non-synaesthetic individuals recruit universal cross-sensory associations." [4] (page 363).

There are at least 80 registered types of synaesthesia, according to Sean A. Day[3] and the experiences from varieties of sensory pairings are so different. Thus, synaesthesia is an extraordinary source to study human perception. An interesting example of synaesthesia is that of the designer Michael Haverkamp[4], who takes advantage of his condition at work, by testing the car according to his three synaesthetic pairings: touch, smell and sound. He would tie his eyes closed to sharpen other sensations. In his book titled 'Synesthetic Design: Handbook for a Multisensory approach' [5] he notes (page 123): "The results of contemporary neuro-scientific research have spawned psychological as well as philosophical discussions and have stimulated the creation of concepts for fine arts and music, indicating the increased preference for cross-sensory approaches.". Moreover, acceptance of the perceptual differences can be beneficial for tolerance between people and appreciating subjectivity. As Kevin Mitchell states: "There is in fact a rich and under-appreciated diversity of perceptual experience, across all the senses, from a simple level of what kinds of stimuli we can detect, and how, to a much higher level we integrate perceptual attributes of objects into schemes." [6] (page 134).

1.2. Synaesthesia as a transposition of sensory experience

Kandinsky described synaesthesia "as a phenomenon of transposition of experience from one sense modality to another, as in unisons musical tones." [7] (page 56). Very often synaesthetes use their cross-modal experience for creative outcome. An example of transposition of sensory experiences is that of James Wannerton, who has the simultaneous perception of multiple stimuli (sound and words/names) as one gestalt experience (taste). He used his special multi-sensory condition in designing the London subway map 'Tastes of London' [8]. We give another example by taking the excerpt from the book of Van Campen [7] (page 54) about the apparent chromaesthesia or sound-to-color synaesthesia that the famous artists Vincent van Gogh experienced: "a personal anecdote about the music behind his own painting. The artist took piano lessons in 1885 to become acquainted with the subtleties of colour tone. However, his elderly music teacher sent him away soon after he noticed that van Gogh was constantly comparing the sounds of the piano keys with Prussian blue, dark green, dark ochre, cadmium yellow, and other colours. The teacher thought his pupil was a mad-man.".

Current research on synaesthesia can also have societal impact. For example, according with the book [9], Dr. Amir Amedi, from Hebrew University, is using the synaesthesia pairings model for developing sensory substitution devices as "seeing with ears, seeing with touch, seeing with taste", for blind people. Dr. Amir Amedi points out that nature and animal life shows us those examples: "The idea is to replace information from a missing sense by using input from a different sense. It's just like bats and dolphins use sounds and echolocation to 'see using their ears'." [9].

Synaesthesia can also have an effect on the feelings produced by sensory experiences. David Linden, professor of neuroscience, describes "touch" and skin as a "social organ" [10], "through which humans interact with each other, feel empathy, like or rejection and their place in the physical world." Some

[3] www.daysyn.com

[4] https://youtu.be/dj7FNTGonFQ

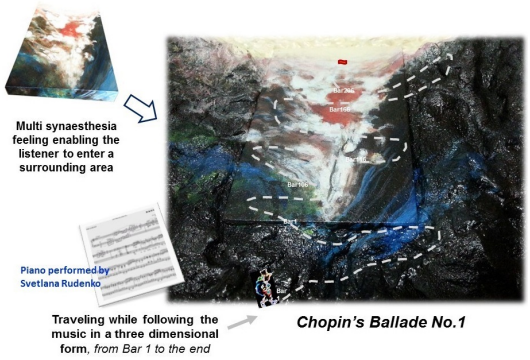

Figure 1: *Ninghui Xiong, Art visualisation of musical texture based on shape and colour, in Ballade N1, Chopin.*

synaesthetes can transfer their tactile experiences or pain into visual images and colours. Artist Carol Steen created coloured visual projections of pain [11]. According to Jamie Ward [1], mirror-touch synaesthetes "scored significantly higher on the 'emotional reactivity' component, which relates to their instinctive, gut reaction to others. Those synaesthetes have more empathetic feelings towards other people and react strongly when shown somebody's wound, medical operations, movies with pain scenes, etc.". Ward continues: "The emotional aspects may be driven by multisensory 'mirror system' involving vision and touch that is enhanced in this variety of synaesthesia." [1].

2. Interviews with artists-synaesthetes: Art on music

2.1. Summary of the interviews

This section gives a summary of the findings obtained from interviews on synaesthesia related to the subject of art on music, which were conducted by the first author of this paper. A more complete report of the interviews can be found online[5].

Ninghui Xiong, artist synaesthete, describes his experience of creating Art visualisation on Chopin Ballad N1: "As an artist, I use my synaesthetic experiences to visualise classical music.". He provided the detailed diagram of his visualisation represented in Figure 1, more specifically the shape of the melody line of the main theme and the colours in reaction to the changing harmonies.

The artist Marcia Smillac created a video[6] with a musical composition written by Maurice Ravel, which is titled Piano concerto in G – II Adagio assai. Figure 2 shows an image extracted from this video. Marcia says "I have a rare form of syneshesia called 'Bi-directional' which means I hear with my eyes and see with my ears." and she added later that "Even more remarkable was finding out that Maurice Ravel who had written the music was also a bi-directional synaesthete."

Another interviewee, the artist Geri Hanh, describes her synaesthesia as: "I see what I hear. The timbre has a shape, texture and a colour, it moves with the direction of pitch in a landscape of time from left to right. All letters and numbers are also in colour, and I taste what I see like mouth feel, not like cinnamon or vanilla – more like eating a sculpture. When peo-

[5] "Art on Classical Music by artists-synesthetes", In the section Lectures of http://www.svetlana-rudenko.com

[6] http://www.marciasmilack.com

Figure 2: *Art by Marcia Smillac, 'Ravel in Pink'. Piano concerto by Martha Argerich in G – II Adagio assai.*

Figure 3: *Geri Hanh, Alfred Schnittke, Symphony No. 1: Senza Tempo-Moderato, Gennady Rozhdestvensky, conductor.*

ple speak, I see it like a ticker tape below their chins. I do not see the timbre of their voices, but rather the colour of the words they say based on how it is spelled". Figure 3 shows an example of the art work of Geri Hanh on Alfred Schnittke.

2.2. Interviews assessment

The three cases of synaesthesia briefly presented in the previous section show that behind the creative process in Art there are strong sensory experiences, stimulated by music with reflections in secondary visual or tactile sensory modalities. The experiences of the interviewees are consistent among each other in the way that the emotional experiences are visualised, i.e., transformed into images. This consistency can be explained by the statement from Farina, Mitchell and Roche [12] that "the neural substrates of synaesthetic associations, once they are consolidated in what is presumably an early critical period, remain 'hard-wired' thereafter and can persist over long periods even under conditions that alter or completely suppress the conscious synaesthetic experience itself.".

3. Audio-visual experiences

Lidell Simpson created Dancing Lights [7], an audio visual digital synaesthetic animation, for the IV Congress of Synaesthesia, Art and Science, Alcala la Real, 2015. Simpson describes his experience as "I have been deaf all my life and I'd like to say that I have never known silence. I learned at an early age that hearing people is not the hearing that I hear. I called it 'Photonic Hearing' before I learned the word 'Synaesthesia' (...) My synaesthesia is primarily sound based. Everything I see, touch, taste, smell, even my emotion gets translated into sounds.". The work by Lidell Simpson is an example of the artistic audio-visual experiences that can be produced through the artist's synaethetic perceptions. Synaesthesia has a key function in the synchronisation of the audio and visual modalities. This section

[7] https://youtu.be/hVKXpezAfjM

Figure 4: *The Eternal Feminine archetype of musical texture, A. Scrabian, Sonata N5, op.53.*

Figure 5: *Synaesthetic Art on Archetype Vertiginous Dances by Tim Layden, Sonata N5, op.53.*

focus on cross-modal associations when the stimulus is music, particularly the concept of music texture, and describes work carried out by the authors of this paper on this topic.

3.1. Musical texture as an inducer of cross-modal associations: Cognitive Musicology

Musical texture is a complex of elements, such as rhythm, melody and accompaniment organisation, related to music structures[8]. Meanwhile, cognitive musicology is a discipline of music science, reflecting on music analysis, perception, mind and imagery, using computational tools. Bulat Galeyev, Professor of physics and philosophy, argues that cross-modal associations are a normal process in music modelling [13]. A recent project has explored this idea and tried to bring together these two concepts. More specifically, Dr Svetlana Rudenko, in collaboration with visual artist Maura McDonnell, introduced the work based on the concept of Cognitive Musicology during the British Neuroscience Association Festival BNA 2019, Dublin. This project, funded by Neuroscience Ireland and Trinity College Dublin, consists of performing music analysis based on cross-modal associations. The music and historic visual images are created using cross-modal associations to match the symbolic representations of the composer. An online video[9] was produced as part of this work on the A. Scriabins Piano Sonata N5. The piano performance and music analysis was performed by Svetlana Rudenko. The paintings are by Timothy Layden, Svetlana Rudenko, Mikhail Vrubel, and Jean Delville. This work also used the archetypes of musical texture described by Susanna Garcia [14]. Figures 4 and 5 represent examples of the cross-modal associations of musical texture in this work.

[8] https://www.oxfordmusiconline.com/
[9] https://vimeo.com/337354023

Figure 6: *4D visualisation of musical texture.*

3.2. Computational model of musical-space synaesthesia

According with recent research on musical-space synaesthesia, the pitch in music can be perceived as having a spatially defined array. For example, Akiva-Kabiri et al. [15] state: "Unlike the vertical and horizontal representation of musical pitch tones in the general population, synaesthetes describe a linear diagonal organisation of pitch tones".

The first author of this paper is a pianist and experiences a type of musical-space synaesthesia. The visual and tactile synaesthetic sensations of musical texture can induce on her the perception of sound as a "sculpture" or "landscape" [16]. By applying her synaesthetic perceptions, she developed with Dr John Dingliana, Professor at Trinity College Dublin, a Computational model of Musical-space synaesthesia: 4D visualisation of musical texture[10]. In this model, the layers of musical elements, such as melody, middle background and base line create a terrain landscape in the synaesthetic mind, reflecting on volumetric perception of sound. The colours assigned to the pitch parameters demonstrate the "chromaesthesia-like experience". Figure 6 shows a snapshot of the 4D visualisation video[11]. The software made in Processing produces real-time animation during a performance, reacting on the audio captured with the microphone. Volumetric visualisation of musical texture is expected to produce a different experience to the audience through the perception of phrasing and timing during.It could also help to solve many technical virtuosity problems in piano pedagogy.

3.3. Tetractys: Musical animations on art

Tetractys is a multi-disciplinary research project that brings together science, music and visual art. The research is grounded on synaesthesia. The colour patterns and shapes of the art works by Sofia Areal are musically interpreted by the pianist Dr Svetlana Rudenko and digitally animated by Dr João Cabral, into synchronised cross-modal perception experience[12].

4. Future directions

4.1. Mental health

Synaesthesia enhanced applications could be useful for education and mental health programs. Anil Seth, Professor of Cognitive and Computational Neuroscience, at Sussex University, conducted an experiment to train non-synaesthetes for colour-grapheme synaesthesia, and stated that after 9 weeks the participants passed the test: "results of an IQ improvement therefore provisionally indicate that cognitive training including synesthetic associations may in the future be a promising new tool for vulnerable clinical groups to enhance general mental ability." [17]. Also, recent studies on healthy ageing and the brain, carried out at the Centre for Vital Longevity, University of Texas, show that engaging hobby activities improve cognitive functions [18] (page 109). This is motivated by the brain plasticity characteristic. Negnevitsky in his "Artificial Intelligence" book points out that "the most interesting finding is that a neural network exhibits plasticity. In response to the stimulation pattern, neurons demonstrate long-term changes in the strength of their connections." [19] (page 166). We strongly believe that digital applications on Art and Music have the potential to provide very stimulating and engaging experiences, where cross-modal perception is stimulated by simultaneous activation of neurons in multiple regions of the brain (in response to stimulation of different sensory modalities).

4.2. Artificial intelligence systems

Artificial Intelligence (AI) systems are inspired by biological models of the neural networks in the brain. For example, significant recent advances have been achieved in applications of natural language processing and visual computing using models based on artificial neural networks (ANNs) [19, 20]. Training systems how to smell is also an emerging field of research. Jordana Cepelewicz [21] hypothesises the possibility of "turning back to the brain for fresh ideas" and "choosing what may at first seem like an unlikely starting point: the sense of smell". A great challenge for AI systems is to synchronise and combine the input from different modalities, such as audio-visual processing. The knowledge about synaesthesia could be applied to design better ANN architectures to overcome this limitation.

5. Conclusion

Studies on synaesthesia perception broader our understanding of sensory experiences and how musical sound could be perceived. In this paper, we give a review about the interaction of senses in synaesthetes' experiences, because we consider that this is an important step in applying the knowledge about synaesthesia into Art and Music. This work includes a summarised assessment of interviews conducted with artists who have this condition. Our preliminary work incorporates concepts from Cognitive Musicology and cross-modal associations of musical texture in the development of powerful tools that enable to deliver music content visually. The hypothesis is that the multisensory perception provides more engaging emotional experiences. We have used these tools to deliver the work on Audio-Visual synchronisation in events of Art Installations and piano concerts. From our own experience and positive feedback we received from audiences, we strongly believe that synaesthesia sensory pairings can be applied as a model to produce more engaging experiences and aesthetic appreciation for Arts and Music. However, in the future it is necessary to conduct more formal experiments to evaluate the advantages of multisensory design. There is also a wide range of applications that can be further explored. In particular, we are interested in simulation of cross-modal perception in technology for healthy brain ageing and training of neural plasticity, including applications with digitally enhanced environments using AR/VR. Synaesthesia examples also demonstrate sensory transpositions, which were already successfully applied for Sensory Substitution Devices (SSD), translating visual information through sound to compensate lost sense for blind people.

[10] www.synesthesia.info/harvard.html
[11] https://vimeo.com/232331357
[12] https://vimeo.com/284938528

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