Artistic Brain: A Complex Nonlinear System as Advanced Neuroesthetic Research

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Abstract

This paper explores brain systems that neuroesthetics and brain-wave art have experimented, in order to consider a complex non-linear system of a brain in terms of art, science and technology.

Semir Zeki created a field of neuroesthetics by trying to study the relationship between art, aesthetics and brain through fMRI technology. Since then, neuroesthetics has attracted the attentions of cognitive neuroscientists and elicited the vigorous discussions of aestheticians and artists. Nevertheless, recently neuroesthetics confronts lots of criticisms and skepticisms. It is involved in a problem that regards a brain of the most complex structure as a functionally specialized linear system. In contrast, artworks that use brainwaves view a brain as a nonlinear system rather than a linear system. In particular, brainwave sonification experiments a brain as a complex nonlinear system, focusing on sound generated from neural impulses caused by the complex interactions of neurons in a brain. Interestingly, EEG and auditory feedback are appropriate elements for exploring a complex nonlinear system of a brain.

Keywords

Nueroesthetics, Specialized Linear System, functional Magnetic Resonance Imaging (fMRI), Brainwave Art, Brainwave Sonification, Complex Nonlinear System, Encephalography(EEG)

Reconsidering the Neuroesthetic Turn in Art History

Most neuroscientists have thought that there is no reason for them to study aesthetics, or aestheticians have opposed introducing neuroscientific research into aesthetics. But in the 1970s, Daniel Berlyne emphasized the role of physical arousal in experiencing aesthetic conditions (Berlyne, 1971). Then, the emergence of functional Magnetic Resonance Imaging (fMRI) in the 1990s triggered combining neuroscience and aesthetics. Above all, Semir Zeki created a field of neuroesthetics by trying to study the relationship between art, aesthetics and brain through fMRI technology (Miller & Miller, 2012). He was originally a neuroscientist studying the visual brain of primates, but since the late 1990s he has studied the neurological basis for the perception of beauty in the arts. As a result, studies of Vilayanur Ramachandran and Margaret Livingstone as well as Zeki were able to draw public attention to neuroesthetics related to creating art and appreciating artworks (Son, Lee, Jung, Jee, & Jung, 2013). Furthermore, some art historians have applied the research results to their own topics and amplified the public interest in brain science. Barbara Stafford urged scholars of visual culture to confront the core concepts of the humanities using the questions presented by neuroscientists and induced artists to engage in this humanities-sciences debate (Stafford, 2007). Even David Freedberg studied with Vittorio Gallese who is one of the discoverers of mirror neurons. Emphasizing that most 20th century art history and art criticism neglected the neuroscientific evidence for emotional responses, they propose a theory of empathetic responses to works of art that has a definable material basis in the brain. (Freedberg & Gallese, 2007).

However, as neuroesthetics is recognized as a successful interdisciplinary research field, more and more nueroskeptics are criticizing it. They regard the perspective of neuroaethetics on art as reductionism or essentialism. Above all, their views have some validity in that most results of neuroesthetics are based on neuroimaging such as fMRI. The researches of Edward Vul and Eric Racine point out the methodological and technical shortcomings of fMRI. Vul thought that fMRI studies of emotion, personality, and social cognition show extremely high correlations between brain activation and personality measures. He investigated how the non-independent analysis overly inflates correlations and disclosed how the data from the fMRI studies could be reanalyzed with unbiased methods (Vul, Winkielman, & Pashler, 2009). On the other hand, Racine criticized the public tendency of blind faith in neuroimaging data. In general, the public cannot recognize the methodological and technical limits of using neuroimaging data in accounting for concepts such as human subjectivity or consciousness. It is apt to create an illusion that neuroimaging such as fMRI can clearly answer complex questions about motion, emotion and perception (Racine, Bar-Ilan, & Illes, 2005).

Despite neuroskeptics' persuasive criticisms of neuroreductionism or neuroessentialism, neurological aesthetic effects cannot be ignored in art history. As Zeki said, the problem of the nature of art has attracted the attentions of cognitive neuroscientists and opened the field of research called neuroesthetics (Zeki, 1999). Conversely, such movements have attracted the attentions of aestheticians and artists and led to vigorous discussions (Onians, 2007). That is why this neuroesthetic turn is meaningful in art history. Nevertheless, the recent criticisms and skepticisms of neuroesthetic research results make us reconsider neuroesthetic turn in art history. As Kate Mondloch said, brainwave artworks such as Mariko Mori's *Wave UFO* are at the heart of such reconsideration (Mondloch, 2016). We will look into the works of brainwave sonification among various brainwave artworks and discuss the significant differences between the system that brainwave sonification has experimented and the system that neuroesthetics has built up.

Neuroestheics Focuses on the Specialized Linear System

Zeki is the first person to coin the term "neuroesthetics". He presented a creative model for our visual brain. In a process where specific visual signals are divided into specific visual areas, each area is specialized. For example, V1, located in the occipital lobe, is the area of the cortex where the information processed from the retina arrives first. Cells with selectivity for specific stimuli such as shape, color, and movement are gathered in the specific compartment of V1 region or the related visual area of the peripheral cortex. In addition, the regions from V2 to V5 process the visual information received from the visual area and perceive an object or a space. Likewise, each visual region is specialized due to the intensive distribution of cells with special functions. Thus, functional specialization, which is an important characteristic of the visual brain, is derived from the extremely selective reactions of cells constituting the visual brain (Zeki, 2003). The visual brain system presented by Zeki is eventually a system that aims to find unchanging features (that is, constants) in the context of various objects and environments. It includes the process of blocking unnecessary stimuli from a number of visual stimuli, in order to express the most appropriate characteristics of visible things (Torabi & Ashayeri, 2011).

Here, in order to clearly find out the visual brain system, it is necessary to understand a thermodynamic system. In thermodynamics, the term "system" cannot but be used strictly because the movement path of energy and matter changes depending on how the system is defined. The system in thermodynamics refers to a precisely specified macroscopic region of the universe, and the rest of the universe except the system is regarded as the surroundings. It is largely divided into an isolated system, a closed system, and an open system. The isolated system does not exchange both energy and matter with its surroundings, and the closed system exchanges only energy, but not matter, with its surroundings. On the other hand, transfers of both energy and matter occur between the open system and its surroundings (Resnick, Halliday, & Walker, 1988). The aforementioned Zeki's visual brain system processes the necessary stimuli extracted from objects only in specialized brain areas. At first glance, it seems to correspond to an isolated system. But, considering a more extended system in which stimuli in one specialized area are electrically or chemically processed and then moved to other specialized areas, it may be reasonable to assume that Zeki's visual brain system corresponds to a closed system or an open system. However, it often involves only linear one-way flow of information, not bidirectional flow. At present, neuroesthetic researches do not deviate much from the functionally specialized system proposed by Zeki, even though they elaborate the art appreciation processes, refine the research methods, or diversify the art genres (Kim, 2015).

Such focusing of neuroesthetics may be a source of concern. It can be seen by comparing the study of Zeki and Kawabata with the study of Freedberg and Gallese. First, Zeki and Kawabata presented various forms of paintings, allowed participants to classify paintings into beautiful, neutral, or ugly, and then recorded their brain activity by fMRI. The results showed the increased activation of the orbito-frontal cortex is associated with the perception of beautiful stimuli and the increased activation of the motor cortex is related to the perception of ugly stimuli (Kawa-bata & Zeki, 2004). Freedberg and Gallese, on the other hand, took Michelangelo's incomplete work *Slave called Atlas* and Lucio Fontana's *Atteza* as examples. When the beholders watched these works, they sometimes found themselves automatically simulating the movement or the emotional expression. The result showed that the activation of the motor cortex is involved in simulation occurring in response to figurative artworks and architectural forms (Freedberg & Gallese, 2007). But the results of Zeki and Kawabata as well as Freedberg and Gallese confuse us, in that it is doubtful whether it is correct to accept the perception of ugliness and the embodyment as the operation of the same brain area. In a situation where nobody knows exactly what happens in each specialized brain area, it might be oversimplified to accept only the outputs resulted from a linear one-way system. Even though neuroesthetics hitherto has encouraged scholars in various fields to take a transdisciplinary approach to the nature of art, now it needs to expand or change systems that have been built around neuroscientists.

Cubists Explored the Complex System of Brain?

Zeki said that "the artist is in a sense, a neuroscientist, exploring the potentials and capacities of the brain, though with different tools. How such creations can arouse aesthetic experiences can be fully understood in neural terms.

Such an understanding is now well within our reach". That is because he believed that the way the brain works is very similar to the artist's way of expressing the world and objects (Huang, 2009). However, since Zeki's brain machinery is grounded on a specialized one-way system that seeks to find unchanging features in the changeable context of objects and surroundings, it is not so simple to conclude that the way of brain machinery is similar to the way artists express the world and objects. For example, Cubism artists such as Picasso did not try to find unchanging features from objects and surroundings, but intended to express the stimuli derived from various perspectives. That is why Cubist painters vaguely expressed objects. However, based on Zeki's brain machinery, Picasso, one of the greatest artists, might have been an incompetent artist who did not fully understand the brain machinery involved in integrating and organizing distorted information (indeed, Zeki evaluated Cubism as failure in terms of neuroscience) (Zeki, 1999).

Here, acknowledging Zeki's belief that an artist can be a kind of neuroscientist, we need to reconsider that Cubist painters may express the brain operating system which is different from the intention of Zeki. Ironically, Zeki said that even though the functional specialization is regarded as the first step to grasp the essence of attributes in sophisticated brain machinery, there is little known about what happens in each specialized system (Zeki, 1999). It implies that each brain region may not correspond to a linear one-way system and that the brain machinery may include extremely complex processes before being functionally specialized. It can be easily understood by considering the example given in complex science. Although a trillion of water particles in a river interact in complex ways, the large volume of water usually flows into an estuary. At first glance, the flow of the river seems to belong to a simple linear system, but the actual processes of the flow belong to a complex nonlinear system. Even the brain belongs to a more complex nonlinear system than a river (Greschik & Schnyder, 1998). Thus, Cubist painters may intend to explore and express the complex processes that are happening in each specialized area of brain. With regard to this speculation, neuroesthetics, which mainly uses fMRI to analyze brain activities, has yet to discover some clues. Rather, in artworks that use brainwaves, we see the possibilities for such speculation.

Brainwave Sonification and the Complex Nonlinear System

Mondloch said that Mariko Mori's *Wave UFO* led a genuine neuroscientific turn in art history. In *Wave UFO*, the visual data is composed of three interlocking rings. Yellow lines in the outermost level represent eye movements. Six egg-shaped objects in the second level signify the right or left brain activities of the three viewers. Each color symbolizes neural states such as blue alpha wave, pink beta wave and yellow theta wave. Small twin silver balls at the innermost level stand for the degree of synchronization of each individual's right and left. Mori, using neuro-imaging techniques tactically, made screen-based representations respond to the viewers' collective cerebral and corporeal activity. That is why Mori's *Wave UFO* shows the neurofeedback loop extended beyond the brain activity of a single participant (Mondloch, 2016). While Mori's *Wave UFO* showed visually the dynamic neurofeedback loop, some brainwave artists have experimented auditorily the dynamic feedback systems of brain.

Brainwave sonification was tried for the first time by the encounter between physicist Edmond Dewan and composer Alvin Lucier. In the brainwave composition *Music for the solo performer* (1965), Lucier's brainwaves were recorded from his scalp, transformed into sound and delivered to loudspeakers scattered in the room. In addition, various percussion instruments were activated by means of vibration derived from his brainwaves (Straebel & Thoben, 2014). Since then, following Lucier's *Music for the solo performer*, various experimental atrists tried to introduce the ideas of neurofeedback into their brainwave compositions. For example, David Rosenboom's *Portable gold and philosopher's stones* (1972) incorporated the brainwaves of four biofeedback musicians into a single music texture. In the composition, a sound producing system was set up by using a circuit that processed not only brainwaves but the body temperature and the skin response of four performers (Rosenboom, 1990). Further, technological developments and decreasing costs of brainwave equipment gave rise to brain-computer music interface (BCMI) research as an interdisciplinary field of study. The BCMI researches have sought to transform brain signals into music rather than sound. Some of the efforts to transform the brainwaves into music resembled *Music for the solo performer*. For example, BCMI-Piano, developed at the University of Plymouth, was an experiment in which users can control the style and the tempo of the composition resulted from their own brainwaves. The performers can change the musical characteristics by changing their brainwaves from beta to alpha or opening and closing their eyes. In particular, alpha can make music by activating the hammer inside a piano (Miranda, 2014).

The hitherto mentioned brainwave sonification makes sound in the process of recording the brain's electrical activities over a period of time. In fact, they show real-time communication in neural networks. All information processing in the brain relies on single neurons sending and receiving neural impulses. The generation of neural impulses depends on the movements of chemical substances and electrical potential differences inside and outside the neurons. That is why the brainwave music experiments a brain as a complex system, in that the audible sound is generated from neural impulses caused by the complex interactions of neurons in a brain. But the aforementioned works of brainwave sonification mostly used the fine-tuned alpha activity. That is because, with closing their eyes and focusing on their brainwaves, performers can produce sound based on alpha activity that represents a state of psychological stability. Meanwhile, some brainwave artworks use various kinds of brainwaves and mix various senses with auditory feedback to generate sound.

Figure 1. Brainwave Music LAB, *Performative Experiments on Human Test Subjects*, physical interaction between the participant and the performer. ©2010 Brainwave Music LAB

Brainwave Music LAB (BMLAB) explores a more complex brain system by transforming the complex interactions of neurons associated with various senses and environments into music. Several interactive works of BMLAB experiment the relationship between a brain, its surroundings and art. *Performative Experiments on Human Test Subjects* show how the various sensory stimuli change the electrical activity of neurons through real-time sound synthesis. As seen in figure 1, the participant is exposed to physical interactions. Various sensory stimuli create a variety of responses in the brain, which in turn create the real-time brainwave music of the participant. In the process, the invisible events happening in the brain of the participant are used as the aesthetic material of the performance, and they stimulate imagination of viewers. On the other hand, the performer, who is physically interacting, is exposed to the brainwave music produced by the participant, and it cannot but influence the performance. The performer chooses actions in tune with the brainwave music (Alastalo, 2009). The other work *Brain Karaoke* is a comfortable interactive environment in which a participant and two live musicians participate in creating sounds in real time. Listening to those real-time brain sounds of the single participant, the two live musicians improvise with their own instruments. In the process, they do not only react to the brainwave sounds, but also give the participant different musical impulses, which have an influence on the brain activity of the participant (Alastalo, 2009). Thus, the result is a complex musical neurofeedback interaction loop, in which the participant can affect the entire music and let his brain freely react to the sounds. It also means that the participant takes part in the building process of the aesthetic result of *Brain Karaoke*. While the performer chooses actions in tune with the participant's brainwave sound in *Performative Experiments on Human Test Subjects*, the live musicians control performance in tune with the participant's brainwave sound in *Brain Karaoke*. In fact, they show the complex interactions of neurons in the areas of sense, thought, and emotion as well as in the auditory area. It eventually means that the neurofeedback loop generated by the collective cerebral activity of the participant and performers or musicians becomes increasingly complex and work nonlinearly.

The other brainwave artist Lisa Park transforms brainwaves into sound waves, in order to understand how the brain works. *Eunoia*, meaning beautiful thought in Greek word, explores complex brain activities relating to states of consciousness. The brainwave data is translated to modulate vibrations of sound in real time. The resulting sound waves make it possible to vibrate pools of water in metal plates placed on speakers. As seen in figure 2, the performer monitors his/her own brain activity during meditation and transposes the frequencies of brainwaves into vibrations of water in metal plates (Park, 2016). As a result, bringing about the sonified and vibrated neurofeedback loop, the interaction processes generate the complex interactions of neurons in a brain. Visual and auditory sensory stimuli derived from interaction between the performer and the object make the interactions of performer's brain cells more complicated, and the interactions of neurons are transformed into sound vibration. Thereby, the performer's neurons accept new stimuli, activate themselves, make new sound vibrations, and influence performer's neurons again. Such a neurofeedback loop becomes nonlinearly complex.

Figure 2. Lisa Park, *Eunoia*, detail of the performer transposing her own brainwaves into vibrations of water in metal plates ©2013 Lisa Park

Interestingly, encephalography (EEG) and auditory feedback used by brainwave sonification is considered to be appropriate elements for exploring a complex nonlinear system of a brain. First, EEG has a better temporal resolution than fMRI, which is more suitable for exploring a complex system of a brain. Many neuroscientists consider the blood-oxygen-level dependent (BOLD) signal used in fMRI a reasonable alternative to confirm brain activation changes, but blood flow and nerve activity have no direct relationship. Time interval between activating neurons and increasing the volume of blood with high oxygen saturation is at least 2 to 5 seconds. That is why if the neural activities change rapidly, fMRI cannot detect actual actions of neurons. On the other hand, EEG senses the electrical activity of neurons at a fast rate and produces data around every 1/4000 second (Satel & Lilienfeld, 2013). Thus, EEG can directly represent the events that occur in our brain cells. The aforementioned example of the complex system can be compared to EEG and fMRI. While fMRI corresponds to showing the appearance of the river flowing from upstream to downstream, EEG corresponds to demonstrating the real-time processes of complex interactions of water particles in a river. Next, the reaction time of auditory feedback is important to explore a complex non-linear system of a brain. Because its response rate is faster than visual feedback, auditory feedback can directly enhance participation of auditory stimuli in the interactions of neurons (Shelton & Kumar, 2010). In the interactive works of brainwave sonification, the participants' EEG sound influenced performers and musicians as well as themselves in real time. That is why the fast responding sense can form a more reliable neural feedback loop between a brain and surroundings, and can make the performances more dynamic. Ultimately, by using EEG and auditory feedback, brainwave sonification makes it possible to explore a complex nonlinear system of a brain more realistically, and intends to demonstrate nonlinear processes and dynamic interpenetrations happening in neurons of a brain in real time.

Conclusion

This study neither deny a specialized linear system on which neuroesthetics focuses nor advocate a complex non-linear system experimented by brainwave art. As mentioned previously, it should be acknowledged that neuroesthetics as a transdisciplinary research has had an impact on art, philosophy, science, and technology as well as art history. That said, some brainwave artworks attempted by artists and scientists can be a meaningful alternative to explore the brain machinery, in that neuroesthetics led by neuroscience recently confronts a lot of criticism and skepticism.

Human brain is more complex than human genome. In a cerebral cortex, there are approximately 125 trillion synapses, and one synapse may contain 1,000 molecular-scale switches. It means that a single human brain may have more switches than all the computers and Internet connections on our planet (Moore, 2010). Neuroscientists seek to identify the complex human brain as a more specific and specialized machinery. However, neuroscientists sometimes make errors due to their desires to clarify complex phenomena in the brain. It can be easily understood by considering the example that Neil Johnson presented in his book *Simply Complexity*. Suppose that someone always sleeps at 10 pm and wakes up at 6 am, but the person has a lot of activity while waking up. On the other hand, a certain alien, who has no prior knowledge of human life, comes to Earth only between 10 pm and 6 am. Supposing that the alien observes the person only during that time, he may conclude that humans will always go to sleep without much activity (Johnson, 2009). This means that when we regularly observe an object, we can believe mistakenly that the object is always in the same state. In other words, it is a case where the actual complexity is lost because the observed temporal interval is not appropriate.

Such an error can be also found in neuroesthetics. The aforementioned specific examples such as a contradiction between the study of Zeki and Kawabata and the study of Freedberg and Gallese or a devaluation of Cubism by Zeki may also be the case of missing actual complexity. Basical-ly, the results derived from using fMRI are difficult to capture actual interactions of neurons. In that context, the complex nonlinear system experimented by brainwave sonification so far has great implications for the brain system constructed by neuroesthetics. Since Zeki began to study the relationship between art, aesthetics and the brain through fMRI, neuroesthetics has relied mostly on fMRI and other neuro-imaging technologies. It is involved in the basic premise of neuroesthetics that brain areas are functionally specialized. However, the functional specialization of brain areas shown by the fMRI cannot include all the complex interactions of the neurons captured by EEG. In addition, neuroesthetics has focused on paintings in many areas of art. It is because, compared to music having temporal characteristics, the information processing of the brain related to painting is linear. It implies that, compared to the visual feedback, the auditory feedback can show remarkably the nonlinear information processing (Wogan, 2013). Therefore, for advanced neuroesthetic researches, it is necessary to experiment a brain as a complex nonlinear system with various technologies and genres. It can eventually be connected to the theme *Bio Creation & Peace*, in that it makes art, humanity, neuroscience and neurotechnology to become partners in advancing our understanding of the human complex condition.

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