A Historical Perspective of the Biofeedback Art: Pioneering Artists and Contributions

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Abstract. The biofeedback interfaces were initially developed for medical reasons and revolutionized the way we represent the body and its functions due to the possibilities they brought to expand, conceptualize, investigate, and present body information through sounds and images. Biofeedback interfaces outside the medical context demand new interaction paradigms that radicalize the relationship between the body and the machine. The appropriation of the biofeedback technology by artists resulted in an artistic-scientific research program named biofeedback art or biosignal art, which involves, above all, transdisciplinary practices. Such a transdisciplinary aspect is explained: biofeedback art is inspired by applied techno-science research while contributing to and informing part of them since it deals with interoception, perception, and cognitive processes in general. Biofeedback art should not be seen only as a specialized technical operation field but also as an area of inventiveness and cultural criticism. The paper presents an overview of biofeedback art, focusing on its emergence in the 1960s and 1970s, and its transdisciplinary contributions. The historical research methodology and a narrative and systematic literature review guide the study.

Keywords: Biofeedback Art · Art and Science · Art and Neuroscience

1 Biofeedback Interfaces

This article presents a historical perspective of artistic practices with biofeedback, highlighting their emergence, pioneer artists, and their contributions. The methodology used to perform the study is hybrid and merges historical research methodology and narrative and systematic literature review. In future in-depth studies, considering the current results, this methodology will be improved to include the participation of women, both artists and scientists. The procedures used to survey, document, and categorize the mentioned artistic practices outline a historiography of art and technology converging with neuroscience. The official history of art and technology has rarely documented biofeedback art in its beginnings; therefore, the history of medicine, mainly linked to the development of medical devices, can provide a complementary source to deepen this research in the future. The primary sources to investigate biofeedback art were anthologies, proceedings, and forums on art, science and technology, human-computer interface

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design, and experimental electronic music; art catalogs and records from museums and electronic art festivals; and also papers, documents, and writings by the first generation of artists who dedicated themselves to the artistic practice with biofeedback. All these sources were considered through techniques of crossing information and snowballing. Because there is no exclusive denomination for "biofeedback art", several keywords as search criteria were used. The Table 1 presents the criteria summary for surveying the biofeedback art.

Table 1. General summary of the criteria for surveying the biofeedback art.

Keywords	Biofeedback art, pioneers of biofeedback art, artistic practice with biofeedback, artistic practice with medical devices, enactive interface, biosensitive interface, affective interface, affective computing, physiological interface, embodied interaction interface, brain-computer interface, brain-controlled interfaces, neural interface, EEG interface, electroencephalographic signals in art, biosignal art, encephalographic creations, biosignal-driven art, cognitive computing and other keywords combined from these previously mentioned	Sources: electronic art festivals documents in general, such as Ars Eletrônica, Artech, #ART, SIIMI, FACTO; anthologies (such as published by Springer and Routledge), proceedings, forums and repositories on art, science and technology, human-computer interface design and experimental electronic music (such as LEONARDO)

1.1 New Interaction Paradigms

"Biofeedback art" [1] or "biosignal art" [2], in the context of this paper, refers to incorporating biofeedback technology into artistic practices. Biofeedback is a technology initially developed for medical purposes and allows the integration of motor and physiological data from the user to a device. This integration inspired the development of a new interface genre that brought about a paradigm shift concerning conventional interfaces, designed since the 1970s predominantly from graphic references to conduct interaction [3, 4].

While in the traditional interface, interaction takes place through mediation based on symbolic knowledge (words, mathematical symbols, or other systems of symbols) or iconic (visual form of images, such as diagrams and illustrations, accompanied or not by verbal information), in the biofeedback interface the biological body is used and the "interaction" takes place via motor (natural and intuitive), physiological and organic responses (conscious and unconscious) constituted in the act of interaction, and required for performing tasks [3].

As an emerging and experimental media, biofeedback interfaces outside the medical context have few conventions to follow and allow free exploration precisely because of it. Many questions remain open, such as the type of language this interface supports and how to guide the user's attention. Because it bases on controlling psychophysiological states and dealing with the focus of attention, new cognitive skills are required [3]. In human-computer interaction, the biofeedback interface receives different names: enactive interface, biosensitive interface, affective interface, physiological interface, or embodied interaction interface. Regardless of the terminology, they all refer to a specific interface based on problems related to the body-mind relationship, which considers the biological body as a literal interface with the machine.

1.2 Art, Body and Biofeedback Interfaces

Throughout the history of art, we have observed different levels of involvement of the body, both the artist and the audience, with the artwork, even though the body as a whole is always required for the execution or fruition of the artwork, once there is no separation between thoughts, sensations, actions and the entire body itself [5]. However, art paradigms changed in the 20th century when the body came to be used as a canvas, brush, support, and platform [6]. With the advent of the use of computers in the art field, the relationship between body and artwork changed due to the possibilities of producing interactive artworks – the body becomes required and essential, and the public acquired a new status, which is "user" or "interactor" [5–7]. But with the use of biofeedback technologies in artistic practices, the body-artwork relationship radicalized, given the incorporation of the biological level of the body. In this case, there is no more discontinuity between the body and the artwork, making them interconnected via structural coupling [8]. A peculiar type of artwork begins to be produced that depends exclusively on the body for its existence and functioning. The body has no longer just the role of a user; it is also part, in the strict sense, of the machinery that builds the artwork.

2 Artistic Practices with Biofeedback

2.1 History: Pioneer Artists

Although biofeedback has been used in artistic practices for approximately six decades [9, 10], only some artists have explored this technology. The reason is that the manipulation of biosignals is complex, involving many techniques and knowledge from many areas, such as the medical, biological, and computational. Artworks employing biofeedback are mainly developed in the context of interdisciplinary research, and unfortunately, they are not well-known and documented and can not be easily found gathered in publications that provide an overview of them [1, 2].

Although the art nourished by the biological body goes back to the ideas of "meat machines" in cyberculture in the 1980s [11], the first experience with a biofeedback device documented dates back to the 1960s. The pioneer was the composer Alvin Lucier (USA, 1931–2021) when he used his alpha brain waves to create *Music for solo performer* (1964–1965), a soundscape presented at Brandeis University (Massachusetts, USA), and considered the first artistic experience with biofeedback [2, 12].

Also, in the 1960s, other artists pioneered biofeedback technologies, developing artworks that contributed to art and science by investigating correlations between human physiology and sound sensory stimuli. Like Lucier, the other precursors are also from the field of experimental electroacoustic music, collaborated with scientists, and pavimented biofeedback art as an artistic-scientific research program in the following decades.

Alvin Lucier. Alvin Lucier was one of the experimental electronic music forerunners and sound installations that explored acoustic phenomena, auditory perception, and physical properties of sound, and much of his work was influenced by science. In this regard, Lucier approached body sciences around 1960, when he began collaborating with physicist Edmond Dewan (USA), who was particularly interested in the interrelationship between music, nature, and science. Dewan was the first to have a human being controlling an external machine from his brain waves. At Cambridge's air force research laboratories, Lucier and Dewan developed a brain wave reading device (see Fig. 1) that gained notoriety and was used to create *Music for solo performer* [12]. Bart Lutters and Peter Koehler [13] highlight the importance of the device created by Lucier and Dewan and how it helped to improve research on electroencephalogram signals conversion into sounds. According to the authors, this technique has been used since the 1930s, but it was only in the 1960s that it became "popular", becoming a tool for use in the field of experimental music.

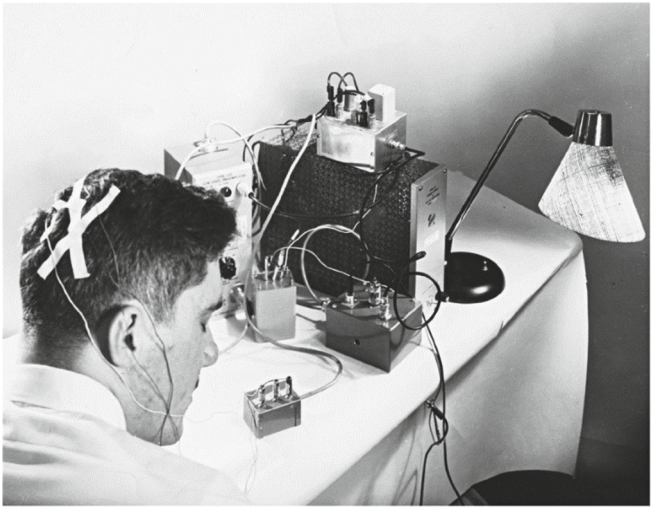


Fig. 1. Edmond Dewan and the acoustic wave control system developed in 1964. Source: Lutters e Koehler (2016, p. 3).

In *Music for solo performer* (see Fig. 2), Lucier sits alone in a chair in the stage center with EEG electrodes tied to his head. The electrodes explore the rhythmic cerebral modulations of alpha bands: "[…] through direct audification with the addition of percussion instruments: cymbals, drums, and gongs that coupled to large speakers; […] bursts of alpha activity cause the loudspeakers to excite the acoustic instruments which, in turn,

activate a disembodied percussion ensemble" [2]. Alpha rhythms, used by Lucier, are brain waves with a frequency between 8 and 13 Hz related to relaxed awareness, lack of focus of specific attention, and a Zen state of relaxation and awareness. The similarity and connection between the mental state achieved during Zen meditation and that required to produce waves of alpha frequencies was established in the early stages of biofeedback research [10, 14].

Fig. 2. *Music for solo performer* (1965 version), by the composer Alvin Lucier. Source: University of Calgary (http://syneme.ucalgary.ca/tiki/tiki-view_blog_post.php?postId=584).

Thomas B. Holmes [12] observes that, except for Lucier's facial expressions and the opening and closing of his eyes, there was no visible index between the performer and the concert of sounds. However, he notes that the alpha waves became more intense when Lucier closed his eyes or became rarer when he opened them – the intensity of the sounds in the speakers could distinguish such observation. Closing the eyes helped

to reach the relaxation state and intensify the production of alpha waves in the brain, and vice versa. Lucien's self-control is guided by sound and, at the same time, by his mental life (see Fig. 3). The artist proposes a correlation for the work as following [12]: increased relaxed awareness/decreased attentional focus/increased relaxation state - increased alpha wave intensity - increased sound loudness (persistent tinnitus).

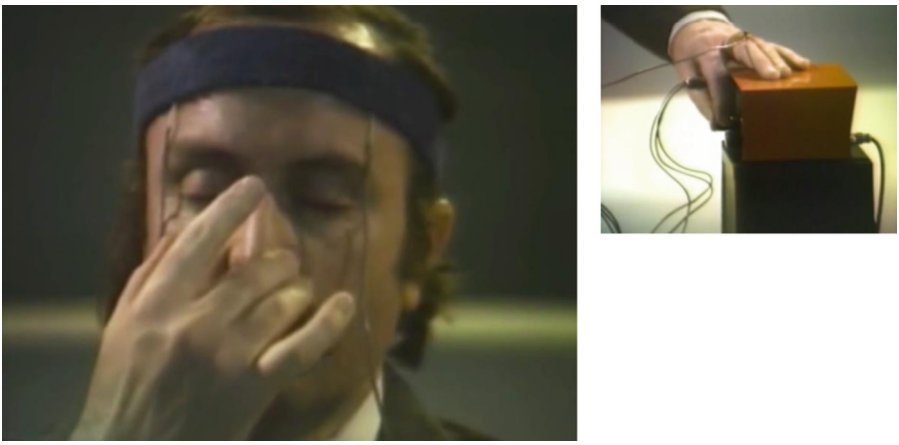


Fig. 3. *Music for solo performer detail* (1965 version), by the composer Alvin Lucier. Source: University of Calgary (http://syneme.ucalgary.ca/tiki/tiki-view_blog_post.php?postId=584).

The Lucier's work conception evokes two themes, brain waves and resonance since the central idea of his work was not just to generate sounds through the amplification of brain waves but to set the vibrating surfaces of the speakers in contact with percussion instruments that, in turn, would create sounds of their own. Drums, gongs, and other small objects were placed under, on top of, or against the speakers [12].

David Rosenboom. David Rosenboom (USA, 1947), another pioneering artist of the 1960s, was a composer-scientist and director of the Laboratory of Experimental Aesthetics at the University of York and the Electronic Music Studios, in Ontario, in addition to having produced several works using biofeedback, also organized *Biofeedback and the arts: results of early experiments Aesthetic Research Center* (1976), which presents the research carried out during the years 1966–1974 by Rosenboom and colleagues, among them Lloyd Gilden and Richard Teitelbaum. According to Thom Blum [10], the book is relevant for the arts, especially for experimental music, because it exposes the concepts, techniques, scientific methods, and research and production processes of the biofeedback art pioneering artists, besides elucidating the thinking that guided their production.

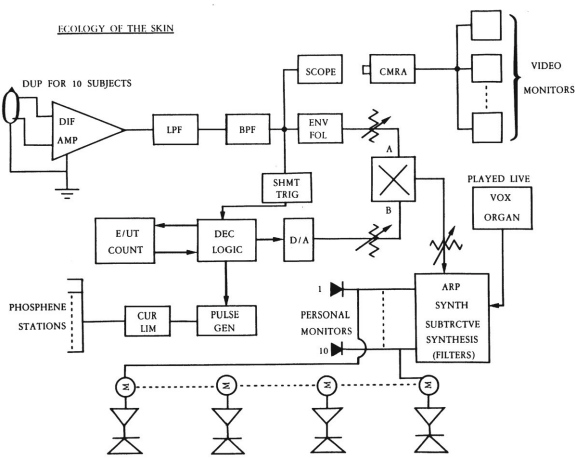
Rosenboom's early experiments used electroencephalographic, electrocardiographic, and respiratory activity measurements to control sound generation modules. The work *Ecology of the skin* (1970–1971) (see Fig. 4) allowed up to ten participants to use electrodes that detect alpha brain waves in connection with a digital logic module. The device designed by Rosenboom for *Ecology of the skin* (see Fig. 5) allowed

tracking the amount of time it took the participant to generate alpha waves – the more time he spent producing alpha waves, the better his control over the synthesis modules of sound connected to the circuit. To maintain the alpha state, the participant had to get positive feedback in the form of greater control over the resulting sound output. Usually, Rosenboom's works requested two or more participants who received visual or aural feedback when they managed to generate alpha waves synchronously – the idea here was to provide, through musical improvisation, a sort of collective behavior [10].

Fig. 4. David Rosenboom and colleagues preparing for the performance *Ecology of the Skin* (1970). Source: http://davidrosenboom.com.

Rosenboom's work offers a unique insight into the blending of Eastern disciplines related to spirituality and meditation practice with Western research methods and scientific physiological monitoring. This combination of knowledge, according to Blum, is the thinking foundation of artists at that time.

Richard Teitelbaum. American composer Richard Teitelbaum (USA, 1939), also a pioneer in biofeedback art, created *Spacecraft* (1967) using biosignals from his body and other participants. Teitelbaum built the artwork with electroencephalography, electrocardiography electrodes, and contact microphones with amplifiers to capture sounds from the heart, thoracic cavities, and breathing, all used as musical biological material



Ecology of the Skin (1970)

Fig. 5. Biofeedback system setup diagram. The electronic setup for this artwork included the ability to adjust the degree of brainwave control over the sound, for each of the 10 participants, according to a simple statistical measure, the amount of time spent per minute producing alpha waves [1].

in real time. The experience combined the participants' conscious musical actions integrated with Teitelbaum's biological actions. In this work, the biosignals operated in an automatic loop system or manually adjusted in the output control for a Moog synthesizer (see Fig. 6).

Fig. 6. Richard Teitelbaum, avant-garde figure and synthesizer pioneer, working with a Moog. Source: https://ra.co/news/72420.

Later works by Teitelbaum, such as the *Alpha bean lima brain* (1972) and *Tai chi alpha tala* (1974), were similarly controlled by brain waves but extended the experience beyond sonification and included "visual display such as strobe lights, sculptural objects, Paik-Abe Video Synthesizer, and the Dan Sandin Image Processor to produce pieces that extend to other media such as martial arts, telecommunications and television" [15]. *Alpha bean lime brain* includes an unusual manipulation of brain waves. These were telephoned from California to New York to make a pot of beans jump during Charlotte Moorman's Avant Garde Festival.

Lloyd Gilden. Lloyd Gilden (USA), another pioneering artist and experimental psychologist, worked with biofeedback, music, and qualitative research in the 1960s and 1970s. Gilden used a questionnaire with questions about the feelings aroused in the participants during the experience with alpha wave measurement electrodes, something

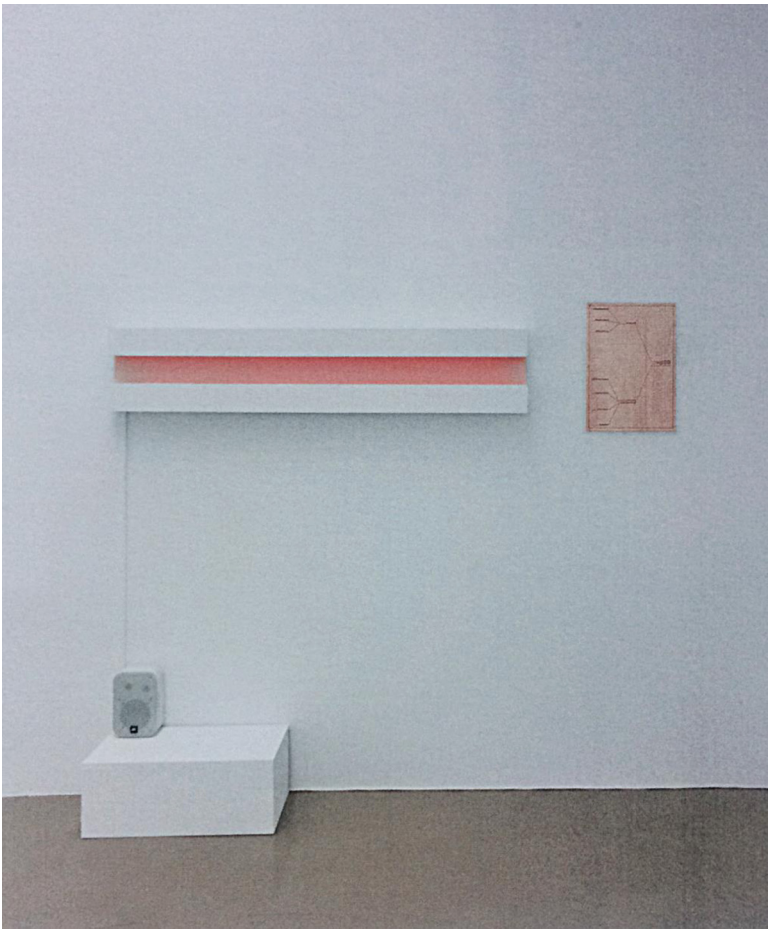


Fig. 7. *Heart beating recording and light* (1970), by Teresa Burga.

very similar to current neuropsychology tests. The artist took information from the questionnaire to remodel the work or theorize about it. Recurring statements were usually associated with feelings of "letting go", "freeing yourself", "avoiding becoming emotionally involved in the production of feedback signals", "blank mind", "not repeating refrains of some activity desired/unwanted", "serenity" and "peace" [10].

Teresa Burga. It is essential to observe that biofeedback art was, for many years, a male artistic practice, a situation recently changed. However, there is Teresa Burga (Peru, 1935–2021), one of the precursors of Latin American art technology who created works in different supports focused on the female body.

She created *Heart beating recording and light* (1970) (see Fig. 7), which was later part of a session in the installation *Self-portrait* (1972) – the artist's most complex work that documented her body through drawings, photographs, medical records, and visual and auditory data, such as the artist's heartbeat recorded for one day. The installation was divided into three parts: "face reports," "heart reports," and "blood reports" and aimed to demonstrate the standardization of the subject in graphic and numerical formats, also a critique of medical images. For Burga, using the heartbeat as a self-portrait is a way of escaping the aesthetic restrictions of art and pointing out another way of relating human beings, information, and technology and suggesting how this type of representation alters the strategies of control. Burga's biofeedback artwork completely differs from pioneering American artists closely linked to experimental music [16].

3 Conclusion

The pioneers in the biofeedback art have something in common, except for Burga: their works are the result of collaboration with scientists and mainly explore the biosignals sonification in the context of electroacoustic music, which uses a device, usually a loudspeaker, that transduces electrical energy to acoustic energy [12]. The pioneering artists' preference for this type of production is explained by Rosenboom [9] who comments that music is a privileged resource to deal with paradigms of apprehension by offering freedom "to work, interact and explore interrelationships within speculative realities" (in this case, to explore the subject's psychophysiology). This forwarding given by pioneering artists to their production will nourish the art practices that followed in the 1990s associated with computational technology.

Still, regarding the correlation between biosignals and music using biofeedback, Rosenboom says, "[…] Events in this psychophysical environment can become symbolic of almost everything that the mind can conceive. Acoustic waves remain relatively abstract through the primary processing stages of auditory perception in the nervous system. Acoustic feature detectors in the auditory nervous system closely resemble sound's physical nature. Consequently, music is an ideal medium for exploring how we hear, process, store, associate, and retrieve sonic images. Within music, it is relatively easy to identify levels of abstraction and explore the processes through which we apprehend and assign meaning to psychophysical events" [9]. Nevertheless, the author notes that although music uses acoustic waves and auditory perception to create psychophysical models, we can explore other possibilities.

Experiments with brain waves and sounds by pioneering artists showed that fruition in artworks produced with biofeedback requires skill (to reach and maintain alpha states, for example), training, and agility. The literature on biocontrol techniques argues that it can be achieved with discipline and practice. However, it is known that the alpha stage is easily disturbed by minor visual and mental distractions and minimal motor effort [2]. As such, the experience with biofeedback devices can be frustrating for some. Being aware of this problem, Richard Teitelbaum [10] even trained the participants of his performances in body awareness disciplines such as yoga and Zen meditation, aiming to improve their skills during the performances.

According to Blum [10], artistic practice with music/sounds and biofeedback was discontinued by the end of the 1970s, but it revived in the 1990s with the emergence of digital technologies. The tension of the Vietnam War in the 1970s, according to this author, reflected a lot on the biofeedback research scene, undermining psychedelia movements and the hope of social application of this type of technology. The following cultural scenario created a different thought dominated by science fiction fantasies and the cyberpunk universe, Blum points out. The artists abandoned using bio-electrodes but carried with them the experiences they had acquired with their use. Some of them even, decades later, resumed their use, as is the case of David Rosenboom, with the interactive works *On being invisible II* (*Hypatia Speaks to Jefferson in a Dream*) (1994), *Ringing minds* (2014) and *Portable gold and philosophers' stones* (*Deviant resonances*) (2015).

The fascination with neural network representations of the brain in the 1960s and early 1970s differs from current motivations, partly because of the political and historical context in which biofeedback technologies emerged and were used. In the 1960s, research in this field and its applications were funded by the United States Department of Defense and did not have the current commercial and entertainment aspect [10]. For Rosenboom [10], at that time, the application of biofeedback technologies in understanding the neurological, psychological, and creative processes of the human being should follow an orientation with social purposes and be used, above all, to improve the "ability to experiment with and bring conscious self-control to the hitherto unconscious neural processes on which mental life is founded."

While pioneers prioritized music to create psychophysiological representations, other artists later invested in different languages and material elements facilitated by the computational medium. Particularly Stelarc, a very emblematic artist, adopts a series of resources beyond the musical ones, although these are present in his works, to create psychophysical models of himself and, like the Brazilian artist Tânia Fraga, both produced biofeedback systems that include robotics elements; on the other hand, Pia Tikka is inspired by the cinematographic language to create what she claims enactive cinema. In general, the musical language is still present in contemporary production, such as works created by artists such as Stelarc, Laura Guerra, Lisa Park, among others. Interest in electroencephalography by artists continues, and it has been widely used to develop audiovisual pieces and artistic practice with emotion induction procedures. In the last ten years, thanks to the popularization of biosensors, which have become economically accessible and easier to integrate into computers, work with biofeedback devices in the art field has increased.

In a few words, biofeedback art is the result of the transdisciplinarity between art and neuroscience and finds parallels with the history of interoception, the body-mind relationship research, and the techniques of detection, evaluation, auscultation, and body percussion in medicine. It is a field of artistic-scientific research in which artists explore new ways of combining technology and the human body physiology that lead us to reflect on our personal experience and physiological and cognitive-emotional responses. There is the hypothesis that biofeedback art is relevant for the embodied mind research program because it introduces complementary arguments for the scientific models of the mind by subverting medical technologies and exploring aspects outside the usual framework of their use. When associated with sounds, images, robotic elements, or cinematic language, biofeedback art throws light and reinforces concepts or philosophical matters of the embodied mind thesis. In this sense, art plays a role in converting concepts into visual and sound forms by creating poetics that connect body, mind, and environment. Furthermore, biofeedback art might be a source of alternative data visualization and a basis for interdisciplinary research on the history of ideas, philosophical psychologies and medical, and visual culture.

The artworks produced by the pioneering artists or those who came later, regardless of the biofeedback poetic implementation, can be discussed employing notions such as systems, competent stimuli, affordances, and self to foster dialogues with neuroscience. As a type of process art, biofeedback art exposes the dynamics between the mind and body and how environmental stimuli influence both; the artwork gains competence throughout the fruition process, and emotionally efficient stimuli cause physiological changes in the interactor's body and alter themselves by these body changes. Because it only exists in an interdependent relationship between the body and the externalization modes of the mind made possible by the biofeedback device, the biofeedback art is a radically embodied system (Anthony Chemero). The structural coupling concept between the interactor/device and the environment (Tom Ziemke) explores a similar idea. As for the "self"-based approach, biofeedback art focuses on self-perception enhanced through competent stimuli or affordances (James Gibson) and enactions that induce the encounter with the self. One of the functions of biofeedback art is precisely this: activating the self through how the interactor coordinates the set of experiences constructed from the body's perceptual and proprioceptive signals induced by the artwork. This coordinated activity opens the involucre of the self. These conceptual approaches illustrate how one could investigate biofeedback art and inform the model we are developing to study it.

The research does not end here. The historical overview was built mainly from the literature available in the leading repositories of scholarly communication. Our study needs to be deepened in art, science, and technology archives and museums to verify women artists' participation in the construction of biofeedback art history. We may find other "Teresas Burgas" utterly invisible in official documents.

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