International Journal of Performance Arts and Digital Media

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rpdm20

Telematic performance enforced by the pandemic: neuroknitting beethoven

Varvara Guljajeva, Mar Canet Sola & Iurii Kuzmin

To cite this article: Varvara Guljajeva, Mar Canet Sola & Iurii Kuzmin (24 Oct 2023): Telematic performance enforced by the pandemic: neuroknitting beethoven, International Journal of Performance Arts and Digital Media, DOI: 10.1080/14794713.2023.2270790

To link to this article: https://doi.org/10.1080/14794713.2023.2270790

INTERNATIONAL JOURNAL OF PERFORMANCE ARTS AND DIGITAL MEDIA
https://doi.org/10.1080/14794713.2023.2270790

Telematic performance enforced by the pandemic: neuroknitting beethoven

Varvara Guljajeva [a,b]*, Mar Canet Sola [c]* and Iurii Kuzmin [a]

[a]Computational Media and Arts, Hong Kong University of Science and Technology (Guangzhou), People's Republic of China; [b]Integrative Systems and Design, Hong Kong University of Science and Technology, Hong Kong; [c]Baltic Film, Media and Arts School, Tallinn University, Tallinn, Estonia

ABSTRACT

The interactive performance *NeuroKnitting Beethoven* was conceived as a live work combining music, neurofeedback and algorithmic knitting to commemorate Ludwig van Beethoven's 250th anniversary and to provide an alternative experience of the classical music canon. This article describes how, due to travel restrictions during the COVID pandemic, the interactive performance became also a telematic project. Apart from the practical considerations regarding the technical execution and adaptation of the work, we focus on the opportunities provided by this transition. We further reflect on how meanings and dynamics ingrained in the technical media deployed by the artists are uncovered and actualised in a new context. Taking the concept of data sensification as our starting point, we examine the capability of biometric data for establishing 'telepathic' connections and the latent imaginative potential of EEG technology that underscores its cultural history. In the context of social distancing during the Covid pandemic, when real-time video and sound connections were found to be an inadequate surrogate for in-person communication, we argue that sensification of brain data could be a means for creating an alternative space of remote intimacy and for providing an experience of 'psychic' connection between the participants.

ARTICLE HISTORY
Received 13 October 2022
Accepted 8 October 2023

KEYWORDS
EEG; interdisciplinary performance; biometric data; telematic art; data experience

1. Introduction

We live in an age where the value of data – sometimes referred to as the 'new oil' – is said to exceed that of fossil fuels (Suarez-Davis 2022, online). This situation is exemplified by the notion of 'surveillance capitalism', which emphasises the extractive properties of the data economy (Zuboff 2019). With the development of 'Internet of Things' (IoT) technology, data harvesting has expanded beyond social media and internet browsing, into our homes, and even under our skin. Devices that register users' biometric data, such as heartbeat, brain waves and daily habits have become a normal part of everyday life.

CONTACT Varvara Guljajeva varvarag@ust.hk Kotka 22-4, 11315 Tallinn, Estonia Varvara Guljajeva @varvara_g
*Equal contribution and correspondence authors.

Besides the use of data for profit and control – known as 'dataveillance' – data can be used for creative and meaning-making purposes. Ever since the advent of physical computing, such as Arduino, and data scraping from online sources, artists have made bold attempts to use data as an artistic material – embedding it into the concept, form, and experience of the artwork. This artistic approach to the use of data, is known as 'data sculpting', or 'data art' (Manovich 2008, online). In addition, emerging concepts, such as information aesthetics, artistic visualisation, and data sensification, all aim to broaden the modalities of data representation. The latter term 'data sensification' resonates most with the performance described in this article because it aims to provide data experience through performance. Similarly, Dragicevic et al. state that data can 'be exploited to express rather than purely communicate particular viewpoints that are related to data' (Dragicevic, Jansen, and Vande Moere 2020, 20).

This article presents a case study of *NeuroKnitting Beethoven,* a work that transforms a classical music performance into a multisensory and modal performance by feeding the performer's brain activity data into a bespoke circular knitting machine, thereby affecting both the knitting process and the real-time visuals that overlay AI-generated videos on stage. The project was initially planned as an in-person on-stage performance, but was instead adapted into a telematic performance due to the social and travel restrictions imposed during the pandemic. As a result of this transition, the meaning of the artwork received a significant impact, which we explore in detail later in this article. Accordingly, the main question that we faced was: How to retain the integrity of the original artistic vision for the performance when the artists could no longer travel and the project was by necessity hybridised?

The NeuroKnitting Beethoven project was commissioned by the Goethe Institute Asia to celebrate the 250th anniversary of Ludwig van Beethoven's birth and was curated by Susa Pop from Public Art Lab. Initially planned as a touring piano and EEG knitting performance (see Figure 1) in seven different locations in Asia during May to June 2020, it was instead adapted into a hybrid event that happened only in two locations in late 2020: Hong Kong Arts Center and Nabi Art Center in Seoul, each connecting to the artists' studio in Tallinn, Estonia. In the first, Linda Yim Chui Chu (Hong Kong New Music Ensemble) performed Beethoven's *Piano Sonata No. 17 – Tempest*; and in Seoul, Jongwha Park (pianist and Professor at the College of Music, Seoul National University) performed Beethoven's *Piano Sonata No. 8 – Pathétique* and *Für Elise*.

This article analyses affective knitting and EEG data sensification in a live performance context. As we have alluded to above, data sensification shifts attention away from the modalities used to represent data and onto the artistic concept and audience experience. In short, data sensification is about experiencing data (Hogan 2018). For *Neuroknitting Beethoven,* we created a complex biofeedback system centred around the pianist's EEG (electro-encephalogram) data. This offers a unique experience whereby music as an aural phenomenon and immediate live performance is treated as brain stimuli, so that the performer's EEG response affects the speed of knitting and the plotted pattern. Through this practice of data sensification we attempt to revisit the affective power of classical music repertoire while also acknowledging the inherently computational principles of knitting (Galloway 2021).

Physiological data, and especially brain data, is unique to each individual person. In this respect, EEG data is particularly fascinating because, since its discovery in the 1920s, it has

Figure 1. A mockup image of the interactive performance *NeuroKnitting Beethoven* illustrating the initial idea.

often been speculated that it may enable something akin to telepathy – a way of tapping into individual or collective psychic energy and thereby establishing psychic connections that transcend material reality (Shure 2018, 224). Thus, this article explores how representation of brain activity can be utilised in telematic performances to overcome distance and distancing, and to create an alternative space of intimacy.

1.1. A century of brain data: technospirituality and universal communication

This section provides a brief historical sketch of scientific research and artistic appropriations of EEG and brain-computer interfaces (BCI) focusing on aesthetics, control and communication in EEG artworks and emphasising its imaginative techno-spiritual potential. In order to situate our work in the 'alpha continuum', we propose to turn to the cultural history and archaeology of the 'new old medium' of EEG and human inquiry into psychic life. This is by no means a comprehensive history of EEG and its artistic applications, but a brief examination of some of the prominent pieces from several decades can put the practice and perception of EEG technology into perspective. Further, it will become apparent how the echo of the original telepathic promise continues to linger today, an aspect that became all the more significant in the midst of the COVID crisis.

The early stage of EEG research was championed by Hans Berger – a German psychophysiologist whose personal experience of spontaneous telepathy early in his life led him to the discovery of alpha waves (Shure 2018, 89) – and later by Edgar Adrian and Bryan Mathews in England, Alfred Fessard in France and Herbert Jasper and Leonard Carmichael

in the US (Robles-Angel 2011, 99). Throughout the 1920s and early 1930s these researchers focused on recording electrical signals in the human brain. This was made possible by the existing graphic representation tools of electrical currents developed by Etienne Marey and Willem Einthoven (Barbara 2006). The affordances of these early instruments have determined the vector of concretisation and standardisation of technology of capture and graphic representation of neural activity. Non-invasive electrodes attached to the scalp and continuous inscription of amplified waveforms thus became a staple, and this technical lineage is still apparent in today's digitally enhanced neuroimaging tools.

In the early days, Adrian and Matthews briefly explored the possibility of affecting the state of the test subject through real-time sonification of alpha waves, predating the idea of biofeedback which would become prominent in the 1960s (Holmes 2014, 90). The discovery of the means of controlling the circular causality of biofeedback opened 'the medium of psychic life' (Borck 2001, 579) to artistic exploration, and sonification was instrumental in achieving this control. Made audible, the brain activity would naturally lend itself to musical applications, influencing the direction that the early artistic experiments in the field would take.

American composer and sound artist Alvin Lucier was one of the first people to notice and leverage the potential for the 'theatrically exciting' performative presentation of EEG apparatus and the effort of 'cognitive labor' of the performer producing alpha waves (Barrett 2017; Lucier 2012, 52; Straebel and Thoben 2014). These aesthetic considerations at once acknowledged the clinical roots of EEG technology and resonated with the Cagean approach to musical performance as a form of labour (Lucier 2012, 44). His 1965 piece *Music for Solo Performer (for enormously amplified brain waves and percussion)* is widely considered to be the first artistic application of EEG data. The piece required the performer to reach a required meditation state which resulted in a steady 8–13 Hz oscillation amplified and routed to multiple transducers that activated a spatially organised 'array of otherwise performerless percussion instruments' (Rosenboom 1999, 10) and everyday objects (Lucier 2012, 53).

In the late 1960s, the cybernetically informed idea of biofeedback, understood as an association of the incoming stimuli with one's mental and physiological state (Shure 2018, 164), came to the fore. It became possible to consciously steer and adjust one's neural activity until the desired state was reached. The ability to influence the interplay between mind and body, input and output of the cybernetic 'black box' (Nijholt and Nam 2015) extended the range of potential uses of EEG technology (Robles-Angel 2011) and influenced the direction of subsequent artistic experiments (Teitelbaum 1976).

By then EEG technology had become sufficiently established to be considered of interest for its clinical, scientific, military and even spiritual applications (Kahn 2013, 97). Joe Kamiya, one of the pioneers of biofeedback, noted the similarities of EEG experiments to Zen meditations (Shure 2018, 167), and attendance at EEG conferences became popular with hippies. EEG epitomised both the techno-optimism of the Space Age and the syncretic spirituality of the New Age as a technologically sophisticated tool for exploring inner and outer cosmos, attracting (among others) artists, musicians and science fiction writers who envisioned different ways of actualising the potential of this technology (Lysen 2019, 37).

One of the archetypal works of that era that embodied this sensibility is *Ecology of Skin* (1970) by the US artist and researcher David Rosenboom. This interactive audio-visual installation took EEG and EKG and mapped them onto multiple audio-visual outputs (Rosenboom 1999, 57). This work pioneered the use of digital logic modules for mapping and simultaneously accommodated several participants in a multi-agent BCI setup. Centred around the notion of biofeedback, it invited the participants to attain a state of meditation through positive feedback, gradually gaining a proportionally larger degree of control over the sound and visuals.

As with another emerging field of the time, that of artificial intelligence, EEG had, by the 1980s, entered a period of stagnation known as the 'dark age' of EEG. During this period the combination of limitations in available computational power and the crisis of ideas put the practicality of research into question (Lysen 2019, 52). Nevertheless, EEG research rebounded in the 1990s, heralding – in George H.W. Bush's words 'the decade of the brain' (Borck 2018, 2). EEG artworks of the 1990s took advantage of previously unimaginable computational resources. For example, *terrain_01* (1993) and *terrain_02* (1997) by the German media artist Ulrike Gabriel focused on EEG as a medium of communication rather than control. *terrain_01* used it as a means of indirect communication between an EEG headset-wearing participant and a biocybernetic colony of miniature light-sensitive robots (Gabriel 1997, online). The 1997 work *terrain_02* added another human participant into the mix so that the resulting alpha waves could be compared and mixed, adding to the intricacy of the resulting interactive model.

One of the representative EEG artworks from recent years is *EEG Kiss* by Karen Lancel and Herman Maat (2014–2022). *EEG Kiss* explores the possibility of digitally mediated intimacy in a series of socially and technologically constructed orchestrations – hybrid installations/performances (Lancel, Maat, and Brazier 2019, 209). Lancel and Maat's performative scenario featured a couple sharing a kiss while wearing a multi-user BCI setup that 'measured' the intimacy between the spectators-turned-performers. The rest of the audience was offered a voyeuristic audio-visual spectacle of sensified biometric data, a peek into the intertwined mind-bodies. Critically reflecting upon questions of intimacy, privacy and data representation, Lancel and Maat's work is both an excellent example of the sensification of biophysical data and of the datafication of affect and affection.

EEG still fascinates scientists, artists and general audiences today. A century since its inception, the technology has undergone several cycles of popularity and hype, each stage of renewed interest juxtaposing imaginative futurities and the vicissitudes of its history. For artists, the principle of EEG has proved to be intuitive and straightforward enough to spark creative experiments while retaining its mystique and profundity. Since its inception, the techno-spiritual aura of EEG continues to attract more 'alpha adepts' (Kahn 2013, 98) even after its initial novelty has faded. The vision of a universal bioelectric language persisted throughout the history of EEG, and artists continue to probe this speculative potential of biodata. This becomes particularly apparent when looking at the sweep of biophysical data works that were produced during the COVID pandemic, many of which used EEG and sometimes in combination with other sources of data.

1.2. Biometric data for closing the gap of social distancing

During the pandemic, social lockdowns were initiated in most countries and so all cultural organisations were required to remain closed. Those working in cultural production had to adopt various ad hoc tactics to prevent a catastrophic collapse of the field. Standard solutions included off-the-shelf streaming applications, like Zoom, Teams, Youtube, Instagram, etc; Matterport and Google Arts & Culture for spatial 3D scans of the exhibitions; Mozilla Hubs for native virtual exhibitions in the metaverse; and, of course, standard web development tools allowed ordinary media content to be posted on websites. However,

> … these formats offered very little audience participation; or to be more specific, the public was largely put in the role of online content consumers. The question thus arises: How are we to facilitate audience participation and belonging in creative processes during a pandemic? (Guljajeva and Canet Sola 2021, 78)

For better audience engagement one needed a tailor-made solution, and this carries the burden of a commission budget, longer development time, and higher risk. In this situation, performative formats were among those that were hit the hardest, and following the onset of the pandemic artists and creators found themselves urged into utilising a variety of virtual, networked and telematic scenarios, some of which featured BCIs and other forms of biofeedback technologies.

One such experiment was *The body in\verse* by Alan Macy, Mark-David Hosale and Alysia Michelle James. In 2021, at the peak of the pandemic, they created an interactive online performance that combined AI, biophysical sensing and data sensification while also directly engaging with the idiomatics of the 'new normal'. This online interactive dance performance is a meditation on the loss of authentic stimuli in the technologically mediated world. The structured piece would begin with a generic 'zoom conversation' between the performer and the audience members that would gradually increase in emotional intensity, thereby setting the overall tone of the performance and altering the emotive state of the performer (Macy, Hosale, and James 2021, online). The affective response and its somatic aftershocks are captured and measured with an array of biophysical sensors that map the emotional and physical state of the performer onto valence/arousal axes. The AI-driven, multi-modal interactive system would then generate text, sound and visuals to accompany the dancer as she attempts to follow the verbal communication with an impromptu choreography.

DANCEDEMIC by Ellen Pearlman was another project concerned with the ever-multiplying boundaries and the dancing bodies that attempt to overcome them. Originally envisioned as a performance art festival focused on questions of migration and biopower, at the onset of the pandemic it was reimagined as a networked open call (Pearlman 2022). Those who answered the call were given a biosensory apparatus, emotiBit, which enabled them to stream their chosen biodata and live video to their distant collaborators, who would then process and interpret the data visually and sonically. The resulting output was then streamed to a platform designed specifically for low latency real-time streaming purposes so that the audience could enjoy the performances and communicate with each other. Ellen Pearlman notes that *DANCEDEMIC* was an adaptation of a framework she had developed for collaboration in live media arts, enabling the mobilisation and

amplification of existing connections between artists, dancers, musicians, engineers and theatrical producers as a response to the global lockdown (Pearlman 2022). The role of biometrics, already present in the original pre-pandemic vision, was thus further emphasised to close the gap between artists, their collaborators and audiences.

Certainly the COVID-19 pandemic created a new sense of urgency for digital innovation in the cultural sector and beyond and led to many changes in practice. In our opinion, the biggest challenge with online and hybrid events is the recreation of physical presence and personal contact. With our art project *NeuroKnitting Beethoven,* we explored how biometric data, and EEG data in particular, can convey a sense of presence and improve audience engagement in a telematic performance. We cannot overlook the increased technical complexity that arises in the case of hybrid events (where not all parties involved share the same physical space). Connecting distant artist(s) via Zoom while the audience remains in the physical space does not usually excite the public. Hence, there is a need for tangible and intriguing elements to compensate for that absence. In our case, we explored how real-time biometric data can fill the void left by the absence of artists and effect materiality over distance.

2. Neuroknitting beethoven

This explorative study applies a practice-based methodology for investigating an alternative method for experiencing a classical music performance. Biometric (EEG) data and a knitting machine directed by that data were deployed to explore a novel method for experiencing live performance. Corresponding to the necessary transformation of the work from a solely on-stage performance to a telematic performance, the research aim of the project was adjusted to encompass the use of biometric data as a medium through which the gap between audience and performer could be closed, thereby offering a more engaging experience.

NeuroKnitting Beethoven served as the case study for these research questions and was supported by a research methodology of observation, analysis and reflection. In the following pages we describe our previous practices, which informed the artistic idea underlying this project, its concept, technical realisation, and interaction system.

2.1. Context: why knitting and EEG data?

The artists behind the *NeuroKnitting Beethoven* project, 'Varvara & Mar' (Varvara Guljajeva and Mar Canet Sola – two of the authors of this article), first deployed data as an artistic material for expressing artistic concepts in 2010 with their artwork *The Rhythm of City*.[1] Using mechanical metronomes ticking in real-time, *The Rhythm of the City* depicts the pace of digital life in the selected cities (Guljajeva and Canet Sola 2011). *The Rhythm of City* is more than just a physical manifestation and sonification of data. It is a work of artistic expression and performativity that deals with the idea of the passive audience. Guljajeva further defines a type of interaction that happens without participant consent as 'post-participation' (Guljajeva 2018).

The artists' interest in more intimate data began with an earlier project, *NeuroKnitting* (2013),[2] in which they applied a user's brain data to create a knitting pattern that was later knitted on a flat knitting machine that they had hacked. Using a wearable, non-invasive

EEG headset, the user's affective states were recorded while listening to Bach's Goldberg Variations. More precisely, three main features were measured: relaxation, excitement and cognitive load, and these were then plotted such that they were unique to each user and each knitted garment: 'Every stitch of a pattern corresponds to a unique brain state stimulated by the act of listening. It means the user's affective response to music is captured every second and memorised in the knitted garment pattern' (Guljajeva, Canet Sola, and Mealla 2012, online). Why was music used as a stimulus? Because music is one of the most potent mood inducers, provoking immediate affective reactions that can be deduced by measuring human physiology, as in the case of cortical brain activity. These affective states are implicit in every human being and can be measured through EEG technology. Through this approach, the artists were able to create unique patterns derived from unique human traits, in other words, personalised, implicit knitting with context and message. In the *NeuroKnitting Beethoven* case, we used a similar approach but in performative settings and in a telematic format where all processes happened in real-time.

Varvara & Mar's interest in knitting began in 2012 with their project *SPAMpoetry*.[3] From a simple intention to hack an obsolete Brother knitting machine, it grew into an open hardware project called *Knitic* (Guljajeva and Canet Sola 2014). And in 2014, the artists completed the open design of a circular knitting machine called *Circular Knitic*.[4] By using digital fabrication and manufacturing tools, like 3D-printing, laser cutting, Makerbeam, and Arduino, they have designed an automated and replicable circular knitting machine. Fab Labs and Makerspaces are mainly oriented to hard-surface object production. Meanwhile, the first digital fabrication tool, an electronic knitting machine from 1976, has long ago been forgotten and discontinued. *Circular Knitic*, and the earlier project *Knitic*, aim to integrate textile fabrication into makers' culture, which the artists define as 'soft digital fabrication' (Guljajeva and Canet Sola 2015).

The commission of the *NeuroKnitting Beethoven* project provided an excellent opportunity to try out a bespoke knitting machine on stage with real-time data and interacting with a live music performance. The art project repurposes a textile production machine as an instrument for experiencing a musician's affective and cognitive state. Ultimately, *NeuroKnitting Beethoven* demonstrates the latest stage in the evolution of the artists' practice – a natural continuation from their past works and interests. The next following sections explain this current project in more depth.

2.2. Concept

As mentioned in the introduction, *NeuroKnitting Beethoven* was commissioned by Goethe Institute Asia to celebrate Ludwig van Beethoven's 250th anniversary in 2020. The vision of the curator, Susa Pop, was to offer the audience an alternative experience of the composer's musical repertoire. This was the brief that Varvara & Mar started to work with back in 2019.

Before the COVID-19 pandemic disrupted their plans, the artists had proposed to embed the emotional state of a performing musician, obtained via an EEG headset, into a live knitting process. The main aim was to transform a normal classical piano recital into a multidisciplinary performance applying surprising elements and processes, and thereby to reframe Beethoven's music and enable the audience to find new

interpretations. During the *NeuroKnitting Beethoven* performance, the knitting machine literally transcribes Beethoven's music into knitting, or more specifically, it transcribes the pianist's cognitive state while he/she plays the piece (see Figure 1). Thus, simultaneous to the auditory experience of the music being played on the piano, the audience is able to experience a musician's brain waves through observing the knitting processes – the pace and rhythm of the machine's knitting, the generation of patterns in wool, and so on. In order to help illustrate the transmission of EEG data and to enhance the visual experience of the stage, the on-screen real-time visuals are overlaid with audio-responsive AI videos that apply a pre-generated visual theme. In short, *NeuroKnitting Beethoven* offered an experimental situation where an unorthodox combination of live music, live technological processes, and live visual enhancements were all presented simultaneously on stage.

As we all know, 2020 went into history as the first year of the COVID-19 pandemic – the first year of lockdowns, social distancing and multiple restrictions. Accordingly, the *NeuroKnitting Beethoven* project could not be performed in the same space as the audience and had to be transformed into a hybrid event. This raised the question of how to deliver an engaging and meaningful experience where the pianist, artists with their knitting machine, and audience members were not present in the same space. In order to maintain the core concept of registering and communicating the brain activity of the musician during the performance, an EEG device with a dedicated computer was shipped over to each of the venues (first to Hong Kong and then to Seoul). Everything was set up remotely through numerous rehearsals and virtual meetings. Ultimately, a biometric data-stream would be transmitted across the internet and close the distance between the concert venue and the artist's studio where the knitting machine was located. The technical details are introduced in the next part.

The performance thus took place in two locations: the concert venue where the pianist performed Beethoven's music while wearing an EEG headset, and the artists' studio where the knitting was happening simultaneously (see Figure 2). Multiple camera streams of the knitting processes, and a combination of on-site and distanced performative elements stitched the experience together for the audience. Of course, the online audience had a somewhat different and likely less emotional experience compared to those who were able to be present on-site.

2.3. Performance flow and technical realization

NeuroKnitting Beethoven is a technically challenging, novel, and multidisciplinary art project that combines neuroscience, streaming technology, AI, digital fabrication, physical and creative computing, art, craft, and classical music. The telematic aspect of the project added an additional level of complexity to the project. We would like to stress that all processes in the performance – from EEG data capture to knitting – happened in real-time.

Figure 3 describes the relationships of multidimensionality, performance flow, system architecture, and processes within the project. As depicted in the schema, the performance had two main interconnected places that exchanged brain data and numerous video streams in real-time: the concert venue with a real audience, and the artists' studio with an automated knitting machine. The performance was also broadcast online, adding a third dimension to the event.

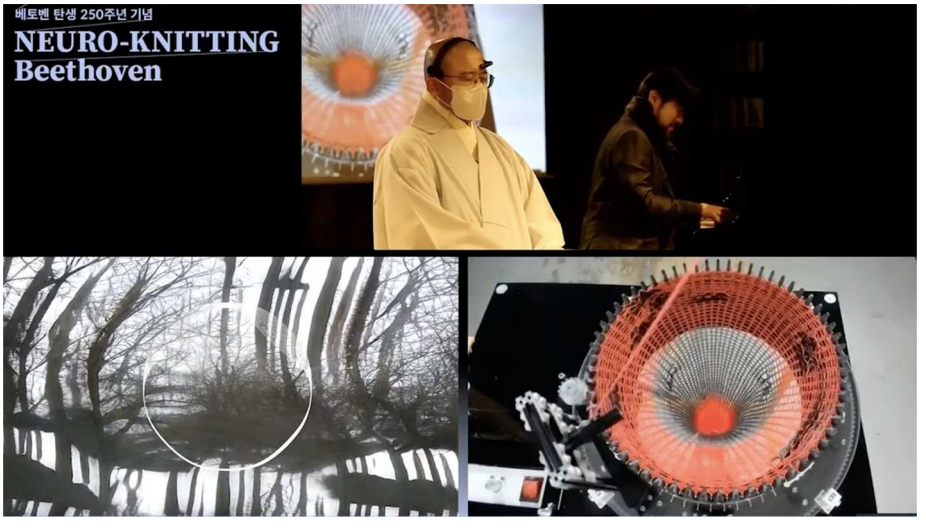

Figure 2. A screenshot of the *NeuroKnitting Beethoven* online stream. The camera view of the performance at Nabi Art Center in Seoul, where the monk who is present wears the Brain Computer Interface (the involvement of the monk is explained below); a video of the affected knitting process streamed from the artists' studio; and thematic audio-reactive AI-generated videos overlaid with EEG data visualisation.

Starting with the concert venue where the in-situ event took place, the audience could enjoy a live classical piano recital accompanied by two different real-time brain data visualisations projected on the wall. One was a raw biometric data visualisation overlaid onto thematic AI-generated audio-responsive videos, and the second was a video stream from multiple cameras capturing the knitting process being affected by the performer's brain data in real time. Camera feeds were managed by an open-source streaming software OBS. The EEG data stream, or more precisely the concept values of attention and

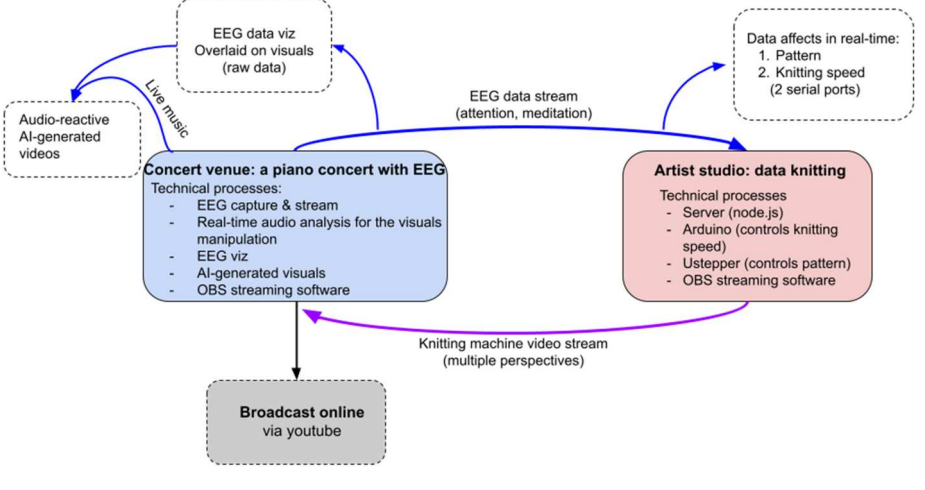

Figure 3. The interconnectivity, technical processes, and performance flow behind the *NeuroKnitting Beethoven* performance.

meditation, were communicated via the internet using UDP from the concert venue to the artist's studio – the artists shipped custom-made software and an EEG headset to the venue for this purpose. This data then controlled the Circular Knitic machine via Arduino and uStepper, and thus, enabled the materialisation of telematic connection, data experience and performativity.

The non-invasive EEG headset used for recording the user's electrical activity while performing was a NeuroSky Mindwave Mobile2. NeuroSky's Software Development Kit (SDK) processes the raw data to extract two high-level affective features: 'meditation' and 'attention'. Meditation was mapped to the speed of the knitting machine: the higher the mediation level, the faster it knitted, while attention determined the pattern. The artists calibrated the spraying of dye onto the yarn to an attention threshold in order to visualise the peaks of the performer's focus. In other words, the greater the attention, the denser the pattern. All these processes were in real-time and simultaneous with the concert performance – the pianist's brain waves were thus plotted into the garment in real-time (a monk wore the EEG headset instead of the pianist for the Seoul performance – see below).

The artists developed a custom-made software architecture for the project. The installation uses a hybrid architecture composed of three software components, all in different programming languages. First, in the concert venue computer, the Python script connects automatically to the Bluetooth EEG headset when it is switched on. The headset then starts to receive brain data from NeuroSky SDK and sends it over UDP to localhost and to the artist studio's public IP. Next, a node.js web server in the studio machine receives the UDP packages containing the EEG brain data. A simple web interface for human monitoring was also developed. The same server code controls the knitting machine and the dye-spraying mechanism over the serial ports. Finally, a Processing sketch running in the concert venue machine creates the brain data visualisation and controls the visuals created with Stylegan2.

When it comes to the interactive system of the artwork, there are two separate parts: one mapped brain data to the physical performance of the knitting machine, and another was responsible for the EEG raw data visualisation on the screen together with the premade videos. The first mapping happened in the artist's studio, and the second in the concert venue. Such interconnectedness was designed to enable the audience to experience the performer's inner state from multiple perspectives: visual and material. By wearing an EEG headset while performing, the pianist could influence the physical object – the knitting machine – and determine the knit pattern. While the on-screen brain data visualisation used raw data, the meditation and attention state of the user (alpha and beta brain waves) were mapped onto the knitting processes. Furthermore, the knitted garment that resulted from the performance can be seen as an alternative archive that memorises performance and its psychic energy as a pattern (see Figure 4).

Regarding the complexity of this telematic interactive performance, for this project the artist's *atelier* was temporarily transformed into a broadcasting studio (see Figure 5), where the knitting machine was captured with three cameras (studio view in Figure 6). There were numerous rehearsals with the technical team of the concert venue: first to adjust the data connection and all video streams and outputs; then, the tests with the performer to get him or her used to wearing an EEG device while playing the piano, and for the artists to understand the biometric data's effect on the knitting processes and the visual part on the second screen at the venue. In the second concert location, in Seoul,

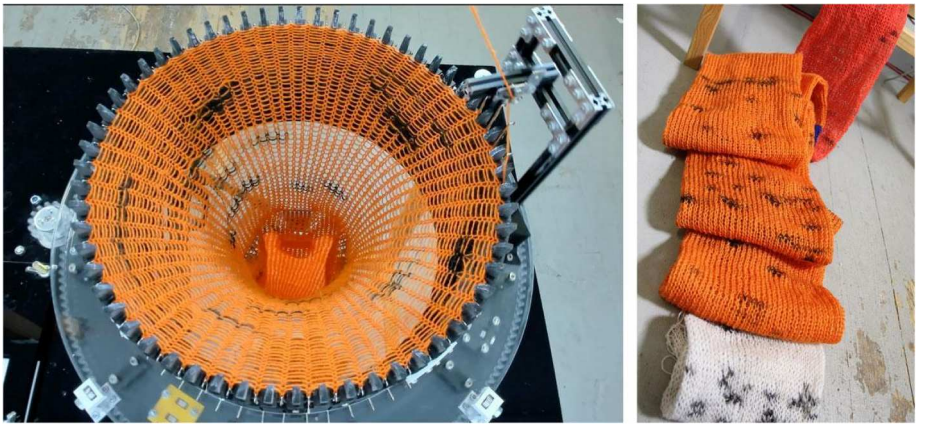

Figure 4. From the left: ongoing autonomous knitting process of *Circular Knitic* (top view), and final result as a garment with a pattern depicting the affective results of the performance.

as a last-minute change, the pianist decided not to wear the headset himself and instead invited his friend, a Buddhist monk. We understand that he found the EEG device an unhelpful distraction while playing.

The use of mechanised sprayed dye/paint to create patterns in the knitting during the performance added to the challenges for the artists. The mechanics of the knitting process became more difficult as the sticky paint made the yarn less smooth and less slippery as it passed through the mechanism (see Figure 7). Whenever the performer's attention peaked, the spray function would trigger automatically (the yarn dyeing process), and the sticky dye caused greater friction. The knitting process is rather complicated and vulnerable to breaking down even in normal circumstances, especially on a self-made machine such as *Circular Knitic*. Accordingly, the knitting had to be monitored constantly

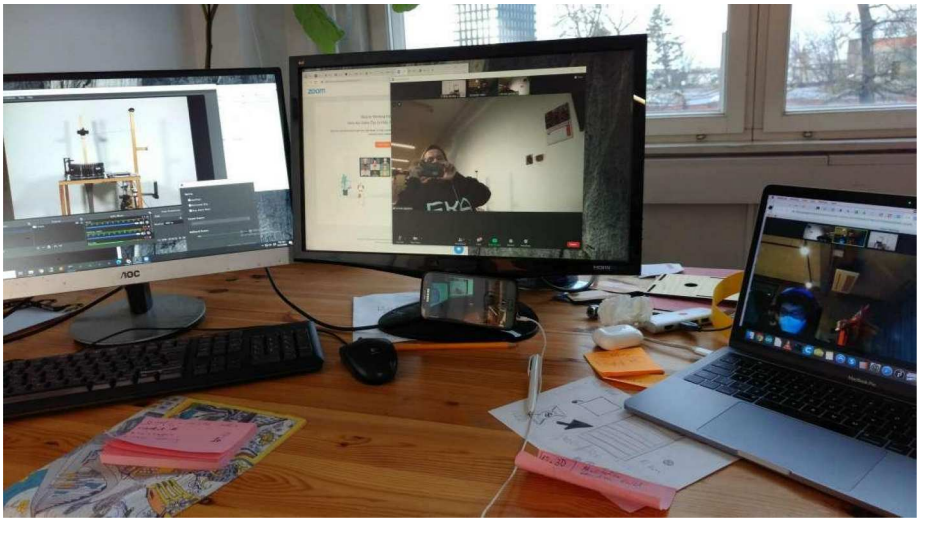

Figure 5. Artist's studio desktop view with multiple streaming platforms on two different machines.

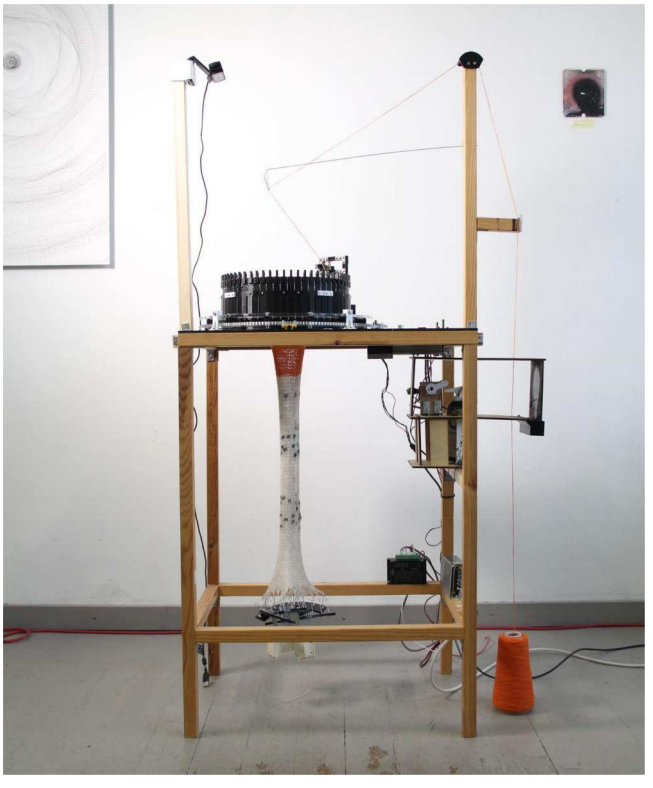

Figure 6. Autonomous knitting machine *Circular Knitic* knitting the brain data of the performer in the artist's studio.

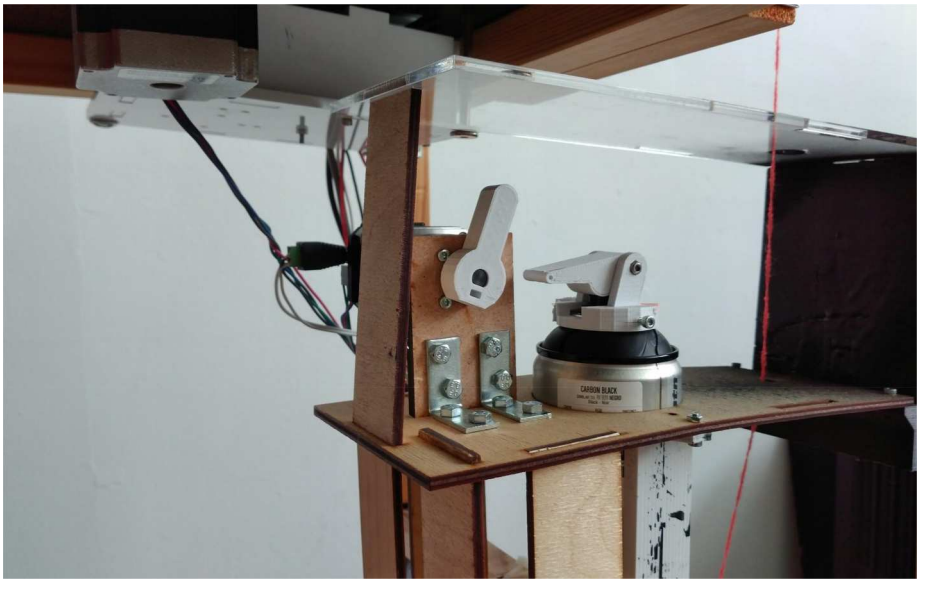

Figure 7. The custom-made yarn dyeing mechanism activated during peaks of attention.

and calibrated for each user whose physiological activity would be knit. For example, in Hong Kong, when the pianist wore an EEG headset, during complex musical passages the attention increased while meditation declined. This was perfect for knitting: knit slowly while spraying only at the peaks of attention. In contrast, during the performance in Seoul, where a monk meditated while wearing the headset, knitting happened at high speed with a lot of pattern generation throughout. The fact that his meditation and attention levels constantly stayed high was not ideal for knitting and the system had to be recalibrated to cope with these intensities.

3. Discussion

Because every individual's physiological data is different, this article does not specify the precise normative values for attention and meditation levels, which require personalised mapping. Different EEG data mapping was used for the knitting in each location and it proved important to understand the idiosyncrasies of each performer's brain data and affective state. As mentioned, a monk wore the BCI instead of the pianist in the Seoul venue. Before the performance, the monk told us that his mission was to confuse the machine. In this he succeeded: as an experienced meditator, both his meditation and attention levels remained constantly high and presented an additional challenge for the artists who needed to calibrate the mapping of data onto the knitting processes with only a limited time available before the performance was scheduled to commence. The artists also had to continue making adjustments during the performance, since the intensive dyeing of the yarn at high speed caused mechanical problems for the knitting machine. Consequently, the system's threshold for meditation levels and attention had to be increased.

In contrast to the monk's intense meditation state, in the Hong Kong concert the complexity of the inner state of the pianist his performance were more readily communicated through the brain data and transcribed into the knitting process. In reflection, based on both the rehearsals and the performance itself, we can say from our observations of the knitting process, affected as it was by the EEG data, that it does indeed provide an additional layer of experience of the actual complexity of playing the instrument. This complexity was reflected in the pianist's high attention and low meditation levels, which made the knitting machine spin slowly while triggering distinct pattern-making. This brings us to conclude that to some extent the knitting machine, normally seen as no more than a fabrication tool, became in these performances an instrument for transmitting what may described as the 'psychic energy' of the performance from the stage to the audience, thus augmenting their experience. The garment that was the final material product may thus be seen as a visual archive of this 'telepathic' or 'psychic' energy exchange between the two locations.

The pattern from the two performances demonstrated the distinction in perception and inner state of the two users, but also the experience of performance through knitting – experience that was plotted into the garment to form memories (see Figure 4). When comparing the two knitted tubes, one can easily see the differences between the two concerts: the second has a much denser pattern that refers to the distinct brain activity of the monk who wore the BCI in the Seoul venue. In both venues, the audience was very curious about the knitted garment's length and pattern, indicating their interest and

understanding that the performer's brain data had been transcribed into the garment and that this was both a novel and enhanced experience of music performance.

Knitting with brainwaves represents an innovative use of craft, expanding the field's domain of knowledge and harnessing the power of EEG technology to create one-of-a-kind garments that capture the users' inner mental states. Each piece becomes a tangible memory of the performance, offering a novel way to preserve this artistic expression for posterity. Through this groundbreaking technique, knitting transcends its traditional boundaries, bridging the gap between art and science and paving the way for a new era of creative exploration.

Finally, we wish to consider the use of biometric data as input for interactivity. Can we talk of the brain thus having 'control' over output, or is it a much more limited influence? This question is also addressed by Prpa and Pasquier (2019) and Guljajeva (2020) in their respective papers. Prpa and Pasquier call the point of issue 'the agency paradigm' and argue that

> the participant-artwork interaction is not always built upon the control of the creative output. Often, a participant's brain activity is utilised in the creative output without the participant's awareness of their explicit "control" over the artwork. In this sense, an artist has creative control over the final output […]. (Prpa and Pasquier 2019, 78)

Guljajeva expresses similar views regarding control over output:

> it [the use of biometric data as input] can be described more like an act of participation or even of donating a piece of the subject's mental activity. The audience cannot really control their heart rate, fingerprints, eye or skin color. To some extent, we can control brain data, but not entirely. Therefore, it is not appropriate to apply the term "interactivity" here without any further explanation. (Guljajeva 2020, 639)

From our observations and discussions with the users of BCI during the two performances, we learned that individuals who are very experienced in meditation, such as the monk, are likely to have a higher degree of control over their brain activity and are thus able to deliberately influence the knitting and pattern design. On the contrary, the pianist performing in Hong Kong was sharing rather than controlling her brain activity while playing. This data was reflected in the knitting processes in real-time. Here we can identify a transcription or translation rather than control over the process. The pianist also mentioned that she concentrated on the music while performing, and but was also a little worried that the BCI device might fall off. After numerous rehearsals, her comfort in wearing the EEG headset improved. However, the musician in Seoul ultimately refused to wear the BCI for two reasons: First, he thought the monk had a more powerful brain signal, and second he did not want any distractions while performing.

Regarding the limitations of the study, research on audience experience was not covered. Since we were not physically present at the performance venues, the observations, reflections, and evaluations presented in this article are limited to the artists' observations from the studio and reflections after the performance. Nevertheless, this is valuable domain knowledge (He 2021, 25) because it gives us an insight into how to design telematic experiences that involve physical installations in separate spaces, how to connect them with biometric data streams, and the processes of their material actuation.

The performance used a basic non-invasive BCI with a dry electrode to capture brain signals originating from the frontal cortex. When choosing a headset, the artists had two criteria: first, the device had to be wireless, 'plug-and-play', and therefore intuitively accessible even to an inexperienced user; and second, the BCI should have an accessible software development kit and allow access to raw and also interpreted real-time data. After careful consideration, the NeuroSky device was identified as the most appropriate. EEG devices for professional use provide more data and are more accurate, but also far more expensive, more difficult to use, and their output harder to interpret. That said, and given the fact that this is an art project, we do not consider the choice of BCI to be a limitation.

Although the use of EEG data has become increasingly commonplace, it retains its imaginative potential as a medium for 'telepathic' communication, a universal language, or even a mind control and surveillance tool. Its speculated potential for creating a sense of remote intimacy – evoking sensations that cut across physical distance – resonates with the idea of the 'telematic embrace' that is championed by Roy Ascott, and according to which networking technologies hold the potential to transcend the ramifications of mediated telecommunication (Luckhurst 2002, 1, Ascott 2003, 222–226). This potential for transcendence, whether of infrastructural or linguistic constraints, is precisely what connects the respective imaginaries of telematics and brainwaves.

4. Conclusions

In this article, we have discussed the early development of the EEG field and traced its first appearance in the creative field. Telepathic connection and the idea of brainwaves as a universal language gained a radical and renewed significance during the period of social distancing and remote connectivity that followed the outbreak of the Covid-19 pandemic. During this time many innovative art projects emerged that were aimed, despite social distancing, at creating a feeling of connectedness by deploying biometric data.

The main focus of this article is the case study of *NeuroKnitting Beethoven,* a telematic performance that used a pianist's brain data to influence the mechanical and algorithmic processes of a circular knitting machine. Initially planned as an on-stage performance, due to the pandemic, the art project was transformed into a telematic event where brain data was communicated via the internet and was applied to affect the speed of a knitting machine and the pattern of garment that machine produced. *NeuroKnitting Beethoven* is an excellent example of how creative technology can secure cultural programmes and enable novel and surprising formats. The telematic nature of the artwork brought together multiple spaces in a creative and unique way, enabling the audience to experience how brain data can affect physical matter and processes over distance. The two concert performances emphasise that physiological and psychological data is truly different across different individuals, and can affect performance flow in distinct ways. In Hong Kong it was exciting to achieve an enhanced feeling of complexity in the pianist's musical performance, whereas in Seoul the performance enabled a unique opportunity to witness the disciplined control of a master of meditational practice as manifested in the knitting process.

Data carries different meanings and concepts: it has a central role in dataveillance, and at the same time, is deployed as artistic material. With the advent of sensory technology

and physical computing, the meaning of personal data has become omnivalent. Our inner bodily data can be easily monitored and embedded over the distance in unexpected scenarios. In this article, we described one such biometric data experience delivered in the form of an interactive telematic performance. As proposed by Trevor Hogan, data sensification is data experience throughout a performance (Hogan 2018).

In the end, we briefly discussed the question of agency in the artworks applying biometric data as an input for interactivity. Although brain and bodily data are able to simulate touch and intimacy in telematic scenarios, the term 'control' is here rather abstract because users have a limited understanding of feedback processes, except in the unique case of an expert in meditation intent on challenging the machine that we witnessed in Seoul.

In conclusion, we can say that the pandemic period left us with a legacy of innovative performance formats that aim to reconnect and imitate bodily connection. Very often, biometric data that could be experienced via visuals, audio or even body interfaces was applied. Therefore, we may conclude that the deployment of biometric data increases connectivity between artists and the audience, and that it can help to fill the empty space of missing artists in the case of hybrid events like the present case study. In this paper, we referred to such telematic connections made possible by the deployment of EEG data as 'psychic connections', thus echoing the origin story of EEG and its inventor's life-long search for the mythical medium of psychic energy that could transcend the constraints of other forms of communication.

Notes

1. https://var-mar.info/the-rhythm-of-city/
2. https://var-mar.info/neuroknitting/
3. https://var-mar.info/spampoetry/
4. https://var-mar.info/circular-knitic/

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

NeuroKnitting Beethoven art project was commissioned by Goethe Institute Asia and curated by Susa Pop from Public Art Lab. MSC is supported as a CUDAN research fellow and ERA Chair for Cultural Data Analytics, funded through the European Union's Horizon 2020 research and innovation program [grant number 810961]; HKUST(GZ) Start-Up Fund.

Notes on contributors

Dr *Varvara Guljajeva* is an artist and researcher holding the position of Assistant Professor in Computational Media and Arts at the Hong Kong University of Science and Technology (Guangzhou).

Mar Canet Sola is an artist and researcher. Mar is a PhD candidate and research fellow at Cudan research group in BFM Tallinn University. Varvara and Mar form an artist duo Varvara & Mar since 2009.

Iurii Kuzmin is a PhD student in Computational Media and Arts at HKUST(GZ) investigating sonic interfaces.

ORCID

Varvara Guljajeva http://orcid.org/0000-0002-0261-3121
Mar Canet Sola http://orcid.org/0000-0001-5986-3239
Iurii Kuzmin http://orcid.org/0000-0002-8686-1308

References

Ascott, Roy. 2003. *Telematic Embrace: Visionary Theories of Art, Technology, and Consciousness*. Berkeley: University of California Press.

Barbara, Jean-Gaël. 2006. "Franco-British Relations in Neurophysiology in Edgar Adrian's Era." In *2e colloque international de la European Society for the History of Science et la Société Française d'Histoire des Sciences et des Techniques intitulé "Echanges franco-britanniques entre savants depuis le XVIIe siècle"*, 4-p.

Barrett, G. Douglas. 2017. "The Brain at Work: Cognitive Labor and the Posthuman Brain in Alvin Lucier's Music for Solo Performer." *Postmodern Culture* 27 (3), doi:10.1353/pmc.2018.0003.

Borck, Cornelius. 2001. "Electricity as a Medium of Psychic Life: Electrotechnological Adventures into Psychodiagnosis in Weimar Germany." *Science in Context* 14 (4): 565–590.

Borck, Cornelius.. 2018. *Brainwaves: A Cultural History of Electroencephalography*. London and New York: Taylor & Francis.

Dragicevic, Pierre, Yvonne Jansen, and Andrew Vande Moere. 2020. "Data Physicalization." In *Handbook of Human Computer Interaction*, edited by JeanVanderdonckt, Philippe Palanque, and MarcoWinckler, 1–51. Cham: Springer International Publishing.

Gabriel, Ulrike. 1997. "Terrain_01." Artist Website. Accessed April 10, 2023. lllllll.de/terrain_02_e.html#b0.

Galloway, Alexander. 2021. *Uncomputable: Play and Politics in the Long Digital Age*. London: Verso Books.

Guljajeva, Varvara. 2018. "From Interaction to Post-Participation: The Disappearing Role of the Active Participant." PhD diss., Estonian Academy of Arts. https://eka.entu.ee/shared/429088/GsqzlotFPrFi1tdtAmVX1Wo8cxFWi4iQjntDJcO4n0mE5NAx8K8pef9V3AC9k3IB

Guljajeva, Varvara. 2020. "Exploring Biometrical Data as a Score and Artistic Material, panel by Kelomees, R., Guljajeva, V., Laas, O., Montgomery, S., Aesthetic and User Experience in Biofeedback Art. In *WHY SENTIENCE? 26th International Symposium on Electronic Art ISEA2020*, edited by Christine Ross and Chris Salter, 638–639. Montreal: ISEA International.

Guljajeva, Varvara, and MarCanet Sola. 2011. "The Rhythm of City. Geo-Located Social Data as an Artistic Medium." In ISEA2011, the 17th International Symposium on Electronic Art September 14-21, 2011, Istanbul, Turkey, 1077–1083.

Guljajeva, Varvara, and MarCanet Sola. 2014. "Circular Knitic," 1.0.0, Zenodo, 2014. doi:10.5281/zenodo.6124168.

Guljajeva, Varvara, and MarCanet Sola. 2015. "An Example of Soft Digital Fabrication." In *Crafting Our Digital Futures*, edited by IriniPapadimitriou, AndrewPrescott, and JonRogers, 48–49. London: Uniform Communications.

Guljajeva, Varvara, and MarCanet Sola. 2021. "ENA Participative Art Forms During Pandemics." In *HyMEx Hybrid Museums Symposium Proceedings*, edited by LíviaNolasco-Rózsas and BorbálaKálmán, 78–83. Budapest: Ludwig Museum.

Guljajeva, Varvara, MarCanet Sola, and SebastianMealla. 2012. "Neuroknitting." Varvara & Mar. Accessed September 21, 2023. www.varvarag.info/neuroknitting/.

He, Shiqing. 2021. "Finding the Grammar of Generative Craft." PhD diss., The University of Michigan. deepblue.lib.umich.edu/handle/2027.42/169800.

Hogan, Trevor. 2018. "Data Sensification: Beyond Representation Modality, Toward Encoding Data in Experience." In *Design as a Catalyst for Change – DRS International Conference, Limerick, Ireland. 25–28 June 2018*, edited by C. Storni, K. Leahy, M. McMahon, P. Lloyd, and E. Bohemia, 1410–1424. doi:10.21606/drs.2018.238

Holmes, Krister. 2014. "Hans Berger and the EEG." *Thresholds* 42: 88–97. doi:10.1162/thld_a_00080.

Kahn, Douglas. 2013. *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts*. Berkeley: University of California.

Lancel, Karen, Hermen Maat, and Frances Brazier. 2019. "EEG KISS: Shared Multi-Modal, Multi Brain Computer Interface Experience, in Public Space." *Brain Art: Brain-Computer Interfaces for Artistic Expression*, 207–228. doi:10.1007/978-3-030-14323-7_7.

Lucier, Alvin. 2012. *Music 109: Notes on Experimental Music*. Middletown: Wesleyan University Press.

Luckhurst, Roger. 2002. *The Invention of Telepathy, 1870–1901*. Oxford: Oxford University Press.

Lysen, Flora. 2019. "The Interface is the (Art) Work: Eeg-Feedback, Circuited Selves and the Rise of Real-Time Brainmedia (1964–1977)." *Brain Art: Brain-Computer Interfaces for Artistic Expression*, 33–63. doi:10.1007/978-3-030-14323-7_2.

Macy, Alan, Mark-David Hosale, and Alysia Michelle James. 2021. "The Body Inverse." Artist Website. Accessed September 21, 2023. www.mdhosale.com/bodyinverse/.

Manovich, Lev. 2008. "Introduction to Info-Aesthetics." Accessed September 21, 2023. https://manovich.net/content/04-projects/060-introduction-to-info-aesthetics/57-article-2008.pdf.

Nijholt, Anton, and Chang S. Nam. 2015. "Arts and Brain-Computer Interfaces (BCIs)." *Brain-Computer Interfaces* 2 (2–3): 57–59. doi:10.1080/2326263X.2015.1100514.

Pearlman, Ellen. 2022. "'DANCEDEMIC' in a Pandemic: A New Networked Reality." *Journal of Network Music and Arts* 4 (1): 5.

Prpa, Mirjana, and Philippe Pasquier. 2019. "Brain-Computer Interfaces in Contemporary Art: A State of the Art and Taxonomy." *Brain Art: Brain-Computer Interfaces for Artistic Expression*, 65–115. doi:10.1007/978-3-030-14323-7_3.

Robles-Angel, Claudia.. 2011. "EEG Data in Interactive Art." In ISEA2011, the 17th International Symposium on Electronic Art September 14-21, 2011, Istanbul, Turkey, 99–102.

Rosenboom, David. 1999. "Extended Musical Interface with the Human Nervous System: Assessment and Prospectus." *Leonardo* 32 (4): 257–257. doi:10.1162/002409499553398.

Shure, Caitlin. 2018. *Brain Waves, A Cultural History: Oscillations of Neuroscience, Technology, Telepathy, and Transcendence*. New York: Columbia University.

Straebel, Volker , and Wilm Thoben. 2014. "Alvin Lucier's Music for Solo Performer: Experimental Music Beyond Sonification." *Organised Sound* 19 (1): 17–29. doi:10.1017/S135577181300037X.

Suarez-Davis, John. 2022. "Data Isn't 'the New Oil' – It's Way More Valuable Than That." *The Drum*, December 12. www.thedrum.com/opinion/2022/12/12/data-isn-t-the-new-oil-it-s-way-more-valuable.

Teitelbaum, Richard. 1976. "In Tune: Some Early Experiments in Biofeedback Music (1966–1974)." In *Biofeedback and the Arts, Results of Early Experiments*, Vol. 74, edited by David Rosenboom, 35–56. Vancouver: Aesthetic Research Center of Canada Publications.

Zuboff, Shoshana. 2019. *The Age of Surveillance Capitalism: The Fight for the Future at the New Frontier of Power*. London: Profile Books.