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Neurointerfaces, Mental Imagery and Sensory Translation in Art and Science in the Digital Age

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The chapter focuses on the issue of transmedial and sensory exchange in the context of digital culture and biometric technology. EEG (electroencephalography) and other brainwaves sensing technologies become an increasingly popular tool that allows translation of mind activity into data and sensible forms, such as visualizations, sonifications, and others. But do these forms indeed represent in the best way how the human mind works? Recent connectivist approaches to the body show that there are translations that happen between various sensory apparata within the body that offer observable sensations standing for processes in seemingly unrelated systems – the phenomenon described as sensory substitution. These exchanges demonstrate that whatever may seem unobservable and undetectable from one perspective (in one modality), can reveal itself in another way. This expands the understanding of what can be called the visible and hence redefines the contours of what escapes not only visual representation, the invisible, but also perception more broadly, the unperceivable. Electronic sensing technologies augment the optical apparatus and allow us to talk about not so much observation, but detection, which comes down to identifying signals. Machines do that analogously to the body itself: communication within the body is based on signals sent electrically and chemically. Staying invisible from the optical perspective, this information is sensible and communicable in a different way. Thus, the same problem of translation presents itself both at the level of intention and signal production in the human/operator's brain and body and at the level of technology that processes and interprets the information received from the body.

The practices of collaborative artistic and scientific experimentation open up new perspectives on how to treat cognitive processes that stay optically invisible even to their own subject. Multimedia performances and artistic experiments designed in partnership with neuroscientists pose a question of translation between different sensory modalities, as well as translation between human perceptive apparatus and computational systems. Artistic scenarios help to both localize and expand these questions, challenging the existing conceptions and offering new methods of analysis. Despite the growing scope of neuroimaging application, there are still questions about the relevance of these mechanisms of interpretation to the given material – mind activity. Among the questions to be posed are: Under what condition cognitive states can be equated to images? How do interfaces that engage various perceptual modalities help to represent what and how human mind sees? What does it mean ethically and politically that an inner image of perception could be detected and rewritten back onto the brain or onto another person's brain? Most importantly, what do these interfaces change in human interaction with each other, and how does the artistic approach help to clarify and expand these questions?

Mental images and the problem of mediated representation

The concept of mental image is shared by several disciplines, including philosophy, psychology, neurosciences and others, and can be roughly defined as representations in the mind of situations and objects that are not physically perceived at the moment of the image experience. This can include both imagined pictures and the ones coming from memories of the lived experiences. Today's image theory (an integral field that grew out of theoretizations about the role of visual perception within art history and theory) offers a broader understanding of images that in addition to visual objects also includes distinct sensory formations, such as perceptual images, or inner impressions based on sense data. W.J.T Mitchell and Gottfried Boehm discuss the value of iconicity as a form of thinking, which is both non-symbolic and non-mimetic.[1] Conceived this way, images do not have to correspond to a state of actual affairs (as proposed in the classical picture theory of language by Wittgenstein).[2] Instead, they form a meaning by the fact of presentation, the fact of a traceable, observable change of state. What is important, is how the experiencing subject comes to the awareness of that change. It happens through the act of recognition of the perceptory event itself, by bringing special attention to its appearance. As I will demonstrate below, biofeedback-based technologies complicate what is meant by the very concept of observation. By automatically detecting bio-signals, such as brainwaves or changes in heart rate, they mediate the awareness of those changes: a person recognizes them not when they are felt, but when they are shown by the technology.

Under this extended definition of an image, mental images can include representations in the mind of the outside world not available directly through senses, and any imagined sensorial impressions felt without external stimulus. The question is then whether or not to treat them as real if they are only imagined. Mental imagery's ontological status has been an old problem in philosophy: whether or not these images represent any "reality," or whether they can be treated as true and trustworthy (e.g. Descartes's dismissal of the phantom limb sensations as anything corresponding to reality). More recently the ontological agenda gave a way toward thinking of the nature of both facts and their representations as more fluid and not directly relatable, and thus, what would be more important to consider is the effects produced by representations (both external and mental). Image scientists have been advocating for image agency, or the potential of the image to act upon human perception and thinking,[3] to organize thinking in a diagrammatical manner, and to function as operational tools that guide both the gaze and physical action.[4] To an extent, these conceptions are based on the findings of cognitive neuroscientists about the connections between perception, representation and cognition.[5] The new software-enabled technologies of visualization bring the role of an image to another level – of providing feedback on one's own bodily and thinking processes (that are otherwise invisible). Thus, the way the feedback is presented plays a crucial role in restructuring and reordering the processes of gaining awareness.

The translation of bodily processes into representable forms, i.e. digital models of behavioral and experiential activities, implies a certain level of abstraction and virtualization of the material process. This poses a problem of the virtualization of the bodily experience. The invisible acquires its visible models and thus can be treated as something potentially modifiable, operable. Yet, it is still available to the senses only as virtual. Media theorists, like Anna Munster, argue that such models cannot replace the sense-making strategies of the body itself and the heterogeneity of corporeal and material dimensions of knowledge production in the digital era.[6] Others, such as Mark Hansen, tend to embrace the potential of machinic cognition and its feedback capabilities to deepen the physical sense of self. He points to Merleau-Ponty's famous distinction between the body image and the body schema, where the former is characterized by an understanding of the body through vision as an external object and the latter emerges from the "operational" perspective of the embodied organism itself. According to Hansen, motion capture technologies create extensions not only of the body image, but also of the body schema, allowing, for instance, to "see through the hand" and to facilitate a "self-reflexive experience of one's embodied agency in the world."[7] Yet this experience comes at a price: the same technology shapes the sensations "before the emergence of bodily self-perception."[8] The problem with both Merleau-Ponty's and Hansen's interpretation is that the mental image of the body schema is something harder to pinpoint once they are "images" in a broader sense – sensorial impressions (rather than visual entities).

Although not directly related, these arguments and cautions find productive resonance with the discourse of critical neuroscience. The brain imaging methods serve as an example of a digital model of the body. Visualization of mind activity (as representative of the activity of the body as a whole) is also grounded in framing that activity itself as an image. The point of critique here is that the brain becomes considered as a locus of subjectivity, and images are taken to estimate the psychological state (that can lead to further ethical and legal conclusions[9]). As Jan de Vos argues, images adopted by and circulated through popular culture invite us to perceive ourselves iconographically.[10] Yet since the new imaging techniques rely more on computation rather than traditional form of visual sensing, the point of discussion is not just images, but "statistical maps."[11] While the difficulty of describing mental images is the subjective qualities that complicate their sharing, the "statistical maps", or data-images created with the assistance of machines are limited by the numerical apparatus and the structures of the algorithms applied to them. Yet, since the beginning of application of numerical methods in medical studies, they were considered progressive exactly for the promise of not only discovery, but more efficient communication. Experimental psychophysiology of the late 19 century was revolutionary not only due to its empiricism, but to the usage of the emerging measuring instruments. The founder of the field, Wilhelm Wundt, assigned his students not a scientific problem, but a task of finding applications for the devices, such as tachistoscopes, chronoscopes, pendulums, electrical devices, timers, and sensory mapping devices, that altogether were thought to produce a sense of what Lorain Daston and Peter Galison will later call “mechanical objectivity”.[12]

In the case of brain-machine interaction, the image can be found in the very electric circuit constructed for brain stimulation or for reading the signals coming from the brain. Its design would be an intermediary that would allow certain data to either be counted or not. But the correlations between the initial signals and their “output” are far from being direct.

Visualization of mind activity is grounded in how that activity itself is framed as an image. Yet, the only access to that activity is interpretation of the electric signals that in their nature are dynamic. The image of a mental activity at stake is fluid and is based on continuous comparison of discrete states. At the foundation of that is also the fluctuation of the states of “on” and “off” of extremely complex networks of neurons, often described analogously to flashing (like a photographic flash that is needed to reveal a picture and bring it “to light”). With neuronal “flashing” the basic picture taken is only of the constellation, the distribution of the signals throughout the network at a given moment in time. Since essentially the sensed signals form datasets, their spatial organization is dependent on external parameters. In order to be read or even simply perceived, they need to be translated into a sensible form – a representation or action.

Technically, brain- (or neuro-) imaging technologies such as PET scans (positron emission tomography) and fMRI (functional magnetic resonance imaging) that show structures and areas of activity within the brain differ in principle from the interface technology of EEG (electroencephalogram) that represents dynamics of particular brainwaves. Both PET and fMRI images are based on correlations between brain activity and cerebral blood flow that can be demonstrated via special “tracers” injected in the blood (e.g. positron-emitting radionuclide tracers or contrast dye that lights up while placed in the magnetic field). EEG does not require injections and expensive scanners and tracks the electric activity of the brain as it is.

Electric sensing may be compared to other types of non-visual detection, or “seeing beyond the visible,” for instance, a sophisticated combination of haptic, visual and quantum level perception used in nanotechnology to image surfaces at the atomic level. When a conducting tip of a scanning tunneling microscope (STM) is brought near the examined surface, it is essentially a type of touch: a tunnel is formed through which the detecting electron can “feel” the surface and produce a measurable current. Colin Milburn calls this type of sensing “nanovision”: “looking into itself, nanotechnology looks outward from blindness – and sees otherwise. … It is a way of seeing that lyses the membrane between the technological present and the nanotechnological future.”[13] Vision, the ability to see as the traditional route for acquiring knowledge is here complicated by “seeing otherwise,” seeing beyond the membrane of visibility, beyond the border between the real and the imaginary/speculative/unproven. Image “beyond visibility” works here as an “interior image” (Gerard Milburn), the product of a technologically mediated vision that is neither purely optical, nor haptic. In that sense, it introduces “dreamscapes” of technology and animates “a productive dialogue and conflict between presentism and futurism, between humanistic thought and its other.”[14] Similarly, brain signals processing requires its own sensing mechanism, generating its own sense that goes beyond the visual (even with visual images as results).

Both nanovision and the brain imaging and interface technologies exemplify a "machinic sense", or "machinic vision." According to John Johnston, machine vision presumes "not only an environment of interacting machines and human-machine systems but a field of decoded perceptions that, whether or not produced by or issuing from these machines, assume their full intelligibility only in relation to them."[15] Despite stretching the borders of perception, such type of vision is self-contained, i.e. it creates "maps" that can be comprehended and interpreted only with the knowledge of the logic of the apparatus.[16] Its genealogy can be traced back to such fateful events as the invention of the telescope and other visual prostheses for natural perception that unanchored perception from the field of the human body's natural capacities and became the first technologies used not just as tools, but as direct extensions of senses, and through that – as tools of (literally) *constructive* thinking.

Looking inside the human mind in order to simply create its map (a diagnostic gaze of fMRI scanning) and *activating* the images stemming from human imagination itself is principally different. The brain-map registers the 'state of affairs,' but cannot transmit what kind of inner processing is taking place, what the experiencing subject actually feels and imagines during the process of scanning. Yet, machinic vision can function also in a generative sense, turning from reflection to action. The indistinct feelings and states of mind can acquire more concrete, even material forms (e.g. in their "Brain Factory" (2016) Maurice Benayoun and Tobias Klein fabricate 3D-printed reifications of brain states). The constructive, generative capabilities of neurointerface technology expand the meaning of machinic vision by demonstrating the new types of interpretive action enabled by brain scanning.

Sensory translation in artistic perspective

The idea of translation considered here is not a linguistic one of transference of meaning from one language to another, but a transference of relations, mapping, and 'porting,' akin to porting of a piece of software into another programming platform. Instead of correlations, there are analogies – more dynamic and fluid connections that depend on a more complex network of associative links. The notion of meaning is still important, and yet it is not a meaning in the sense of semiotics, a meaning as the signified, i.e. captured behind a signifier. Mental images – understood in a broader sense, as perceptual events – challenge the binaries of semiotic schematization and hence complexify the concept of translation.

The problem of complementarity between the senses has troubled people for ages. Until the relatively recent neuroscientific studies philosophy could only speculate about the differences in types of perception and in their objects. If one kind of perception is not enough to give a comprehensive idea of reality there would always be something missing from the view. The neuronal firing activity may be treated as a signification system for different kinds of senses and synaesthetic exchanges; figuring it out may be compared to discovering a universal translation code for establishing connection between the outer and inner worlds. Yet, as the digital code studies teach us, the reducability of the information to discrete on/off signals means that it becomes harder, if not completely impossible, to restore the message in its full sense and hence to reproduce its qualitative content. Thus, it is important to understand what exactly may be missing in translation from one sense to another at the level of the biologically installed code.

The “blind” spots of this system have been inspiring for a number of contemporary artists working with neurointerface technologies. Scientific experiments on the brain functions are fundamentally studies of human perceptual experiences; the interest and contribution of the artists, then, becomes to generate scenarios that would open up new avenues of research and problematize existing paradigms.

The types of sensory and mental images translation can roughly be classified in the following way: 1) from images to mental images; 2) from mental images to images; 3) from images to constellations of signals; 4) from mental images to datasets and their interpretations; 5) from mental images to movements; 6) from haptic stimulation to recognizable and nonrecognizable images. This schema is in no way comprehensive and rather serves as an outline for further discussion of translatory practices and particular issues attached to them. Artistic scenarios help both to localize and to expand these questions, challenging the existing conceptions and offering new methods of analysis. Examples can include both the artworks using neurointerfaces, and neuroscientific experimentation done in collaboration with artists.

1. Translation from images to mental images implies the most obvious starting point of perception: creation of representations in the mind of events and objects that have been seen by the subject in one way or another. We remember faces and places visually, which allows us to navigate in the world. This algorithm is seemingly simple, yet there is broad variation in terms of the attention of seeing (or perceiving in general): the details considered as less important may be ignored and not remembered.

2. Translation from mental images to images is also a well known procedure that describes how images, such as drawings, paintings, etc. emerge from imagination: before taking material form and being shared with others they have to be envisioned within an individual mind. At the stage of making them perceivable by others, i.e. turning them into a sensible form, the specificity of the material, medium of expression will affect not only the result, but how it is envisioned.

3. Various machinic vision technologies allow analysis of images that differs from the capabilities of the unaided eye. Aside from the advanced techniques, such as brain-imaging, or electronic microscopy, it was already the tools needed for transmitting visual signals at a distance, i.e. the technology of television, that would enable breaking an image to the flow (or constellation) of electronic signals. In the context of visualizing physiological data it means creation of simulated models that would rely on the established indexical connection with the

original “picture.” The same principle is used in so called visual reconstruction. MRI-based technologies of visual reconstruction can help to reconstruct the image that comes as input to the visual cortex through the retina. As UC Berkeley neuroscientist Jack Gallant suggests, it will soon “open a window into the movies in our mind.”[17] Visual reconstruction establishes correlations between the input images and the observable patterns of brain activity allowing if not to “read” one’s mind, then at least to “see” the recreations of visual images inside someone’s mind. The images that Gallant produces with his software are still quite abstract and blurry, but there are definitely visible correlations between the image shown to the experimental participant and the computer reproduction of that image based on the brain signals of the viewing subject. (Yet, it is still not possible to capture and reconstruct dreams or images appearing without the external input.) Detecting brain patterns corresponding to visual memories is at the center of brain ‘fingerprinting,’ an EEG-based forensic technique for determining the presence of a specific information in the brain that is discovered through the analysis of the brain response to particular pictures and phrases. Used successfully in courtrooms, this technology provokes reasonable privacy concerns, for instance if certain data and codes that reside in the mind could be extracted by hackers.[18]

Neuroscientists admit that perceptual experience consists of an enormous number of possible states. The key for implementing successful studies is to establish a constraint, for example, research the response to concrete types of images. This is where an artistic approach can be helpful, opening up further questions. In collaboration with the laboratory at the University of Oregon German artist Hannes Bend did a project “mYndful,” a study of correlations between visual stimuli and cognitive states. During the study, the electrophysiological activity of 44 subjects was recorded while asking them to perceive and rate their likeability of over 30,000 images on a like-type scale from 1-5 (1-high to 5-low) twice weekly over the course of eight weeks. The goal was to find out the positive response and to create a feedback based app and virtual reality environment to invoke more meditative states. The scientists admit that a clear consensus about what constitutes a meditative brain state is still to be reached, however, there are observations of correlations between this state and increased theta waves.[19] Neuroscientist Michael Posner hypothesized that “frontal theta induced by meditation produces a molecular cascade that increases white matter growth and improves neural network connectivity”.[20]

4. Translation from mental images to datasets, or more simply, detection of brain signals (also used as an element of Gallant’s visual reconstruction research) became immediately inspirational for artists seeking new media of expression in the 1960s. The first artistic experiments with biodata most famously adopted the method of sonification of brain activity. Among the pioneers were the composers Alvin Lucier, Richard Teitelbaum, David Rosenblum, Pierre Henry, and others, who used EEG technology to translate brainwaves into sounds and thus make that internal information external. As the technology becomes increasingly available and accurate, its applications vary widely from theatrical or gallery performance, to installation,

responsive architecture, and locative media. Sonification is often combined with pulsating light and other forms of feedback that serve as a representation of that which is otherwise inaccessible by human consciousness. Marco Donnarumma, an artist specializing in biofeedback, combines brain sensing with other physiological data, such as heartbeat, blood flow and muscle contractions, to generate an intense vibratory and spatialized auditive stimuli. Similar scenarios are activated by other artists working with biofeedback. For instance, media and electronic sound artist Dmitry Morozov (::vtol::), in his experimental performance “The Escalation of Mind” (2012) monitors the brainwave activity, emotional state and facial expressions of an actor who serves as a control voltage generator. The signals are transformed into a unified acoustic and visual environment while the actor is citing fragments from Herman Hesse's “The Glass Bead Game.” Just as the world of Hesse’s novel, Morozov’s performance is governed by the play of abstractions – stemming from the body, the visible and audible forms transgress the boundaries of a particular individual referring to the realm of purely logical connections. Glimpses of pulsating curved lines, meshes of nerve-wires, spirals of light filling the whole stage space and swirling in it as standing lightnings, or rippling in rounds of unstable lines – all of it is accompanied by Hesse’s words about the higher order of connectedness between all phenomena.

Among the theories that explain the formation of mental images in the mind is the Propositional theory that considers mental images to be triggered by thoughts, or propositions (verbal depictions, as opposed to visual images). In Morozov’s performance, Hesse’s text serves not only as a verbal accompaniment, but also as a stimulant for the actor reading the text and producing brainwave signals. A similar effect is possible with the brainwaves based on mental images appearing in response to narrative situations and verbal depictions not only of abstractions (as in Hesse), but of more concrete and even dramatic events. In Ellen Pearlman’s brainwave opera, “Noor,” visual and audio interpretation of real time brain data of an actress is used to immerse the audience into the inner world of a covert activist under the Nazi occupation in France (that this actor is supposed to represent). The story of hiding from capture is read aloud, and as it unfolds, the panoramic display shows the imagery that corresponds to the emotional states of the performer enacting the protagonist’s troubles in her mind while simply walking around the room.

5. Besides visual processes, including mental visualizations of verbal depictions and narratives, brainwave detecting technologies can track and translate other types of experiences (and mental “impressions” produced by them). Scientific research shows that EEG can be used to decode motor intentions from a ‘sender’ brain that can be delivered as commands via TMS (Transcranial Magnetic Stimulation) to the motor cortex of a ‘receiver’ brain, making the receiver involuntary perform a movement imagined by the sender. This type of translation exemplifies one of the most important themes related to brain tracking technologies and worth critical investigation: control. The research itself is coming from the medical field treating sensory disabilities, and in this case it also closely corresponds with the less benign military agendas. There is a short bridge from the brainwave control of a prosthetic limb and a similar

control of a machine/weaponry, or simply another human. Not surprisingly though, the commercial development of these types of interfaces is led by the gaming industry. With the growing market of cheaper EEG tracking devices (or Neuroware), such as Emotiv, the field of neurogaming is increasingly expanding, leading to appearance of more accurate software and hardware, and stimulating conversations of applications in education and psychotherapy (e.g. attention training).

Movement manipulation at a distance attracted artistic interest at the beginning of the networked age (a prominent example is “Ping Body” by Stelarc, in which muscle contraction is stimulated by the activity of remote users online); yet a thought, or an act of imagination, as a trigger for a physical action is a principally different operation, requiring careful exploration of how mental states and imagination at large operate. The closest artistic illustration of this principle (yet without the TMS) is a performance by Ippolit Markelov and his group “12 apples,” in which a dancer’s movements are directed by a ‘sender’s’ brainwaves via muscle electric stimulation. The performer whose brain is being scanned may not be aware of what exactly is being sent, and the choreographic movement becomes a metaphoric form of representation of those inner states.

What is being translated into action may not even be an image in a conventional, visual sense, but a particular state of mind that can yet be represented as a “map.” It is, then, in that sense that it operates as diagrammatical, or “operable” and “performative.” Markelov’s case, engaging “operation” over another human points at the most radical direction of this technology’s application. “Chromatographic Ballads” (2013) by Ursula Damm demonstrates what can be done within the field of visual manipulation. Damm’s installation allows a visitor to direct a software framework with an EEG device and, with that, to transform an image of an urban public space (an image of a busy intersection or a train station presented on a screen would shift, get blurry or change colors in response to the brain signals that themselves are supposed to represent an unconscious reaction to that image). Utilizing similar principle of image control by neurowaves, “Brainscore” (2003) by Darij Kreuh and Janez Janša is an example of an early neurogame (though framed by the authors as a performance). Two operators act in a virtual reality environment through their avatars – abstract floating spheres, sending commands through a system based on operator's brain waves signals and eye movements. Yet, the brains themselves are treated here as metaphorical representations of wider social systems: each area of the brain is associated with a particular field within the internet – global migration of goods and information that directly affect the individuals in everyday life – meterology, stock exchange, media, transport and epidemic diseases. The signals from the particular brain area pinge the selection of webpages on these topics, and from there an abstractly depicted scenario unfolds where characteristics of the information from the websites are transformed into qualities, like texture, form, color and sound. A virtual alternative to the real world is thus created, forming a closed loop system distributed within the brains of the two performers/players: an analog to the whole world, with all its complexities is – literally – mapped onto a human brain.

6. Finally, we come to what is most commonly known as the phenomenon of sensory substitution, or translation between nonvisual (usually tactile) stimulation and optical cortex. One of the most known findings is Paul Bach-y-Rita's discovery of the connections between the optical cortex and electric stimulation of the parts of the body surfaces (e.g. abdomen, back, thigh, and even tongue – that makes it possible "to see with a tongue"[21]). Bach-y-Rita's Tactile vision substitution systems (TVSS) transduce optical images picked up by a TV camera into a form of energy (vibratory or direct electrical stimulation) applied to the skin receptors. The stimuli then travel through the somatosensory pathways and structures to reach the perceptual levels and to form images analogous to the initial input.[22] These images would differ from the flat images that can be felt on the skin surface and are, instead, 3-dimensional, having characteristics of perspective and depth.

Besides its practical application, this research inspires artistic expressions by visually impaired people. An example of that is a series of workshops organized by Jill Scott as part of "eskin" (2008) artistic research on the potential of tactile perception.[23] The concept behind the workshops implied the opportunity for visually impaired participants to create movement-based compositions for a sighted audience. The experiment involved a wearable interface that would provide the performers input about their spatial orientation, as well as gestures of other performers. The sensors (compasses for vibration direction, accelerometers for gesture recognition and ultrasound to avert collisions with obstacles) and actuators were embroidered on the electronic circuit and connected through a Bluetooth network distributed among all the performers. Thus, by communicating with other actors through gesture the participants were trained to create their own movement theatre.

Throughout human culture (from Homer to Borges) blindness has been considered as a source of a special ability to see inwards (however romanticized this view may be). Lack of visual stimuli and more intensive engagement of other senses may not only provoke stronger imagination activity, but allow different types of thinking process itself. Art projects like Scott's bring this agenda to the public discussion, helping us to be aware of the mechanisms of perception and cognition, and suggesting that there is no singular connection between the facts of reality and their interpretations in the mind. Understanding of this split between reality and abilities to create objective judgments about it opens eyes to the possibilities of deliberate distortions of conclusions (including – in a broader reading – ideological manipulation).

In conclusion: artistic epistemologies

Different strategies for interpretation of the invisible processes in our mind, and the designs underlying these procedures encourage reconfiguration of our existing understanding of the nature of cognition, perception, imagination and communication. Deeper analysis of the material basis of cognitive and perceptual processes reveals multiple discontinuities and discrepancies in their functioning. The problem of translation between different senses, considered here, is only one among many others. While the scientists attempt to give a verifiable account of how mental processes work, art offers its own perspective – that of a lived experience. The abstract issues that neurointerface applications raise, for instance control and the ethical aspects around it, such as responsibility, vulnerability, etc., become tangible and personally relevant (even if for a short time).

Transforming the inner data into an object of digitalization gives access to them as data, with a potential to take whichever form thanks to the algorithmically established correlations. Yet, there remains a question of the possible fundamental incongruence between the inner feeling of something and the data representation of it. Artworks as essentially subjective experiences are capable of emphasizing the role of choices about the aesthetic characteristics of these representations and their additional expressive and associational qualities. It is these 'surplus' perceptual characteristics that give the artistic approach not only an experiential, but also an epistemic value. The haptic and proprioceptive connections established through choreographed movement in projects like Pearlman's or Scott's instigate an embodied response, thus generating a different type of knowledge.

The forms of feedback offered by artists often compete with the commercially available devices used in gaming or self-monitoring culture (e.g. the Quantified self movement). This culture advocates a proactive stance on one's self-awareness, calling for using biofeedback as a tool for training the body and mind to perform more efficiently, in accordance with the preset parameters. The framing of a project as "art" changes the perception of what is expected from applying these technologies. The emphasis is placed on experience of awareness itself, without a predisposed agenda of improvement. In a way, there are no particular expectations attached to these representations. In this experience of a shifted perspective on oneself lies another crucial epistemic potential of artistic approach. While being a fundamentally embodied experience, it also becomes a valuable tool in reconstituting one's feeling of the boundaries of the self and the relationship between the self and the other.

As most of the projects discussed above demonstrate, externalization of the internal works as distancing oneself from oneself. Indeed, in many cases the method through which the invisible mental processes (images) become observable is feedback. The participants/actors in performances, such as Morozov's or Donnarumma's, are made to feel one's own body as an external entity. The representations and translations are there to build connection with the nonrepresentable, but the value of this connection is also the awareness of its function through disconnection, through the negation of the conceptual self. The realization of a gap, the discrepancy between the inner and the outer, the subjectively felt and the sharable is in itself a productive feeling that prevents reifications and attachments to either of the sides. While sciences would treat these visualizations of data as banks of knowledge about what takes place inside the brain, and scientifically oriented technoculture would take that knowledge and apply it to everyday life agenda (e.g. self-improvement), the arts would encourage further questions, pointing at the facts that the numbers (and logical analysis of signals constellations and dynamic) can only show that much and would not be relevant for describing qualia, or affective attitudes and associations that may be attached to those states. Yet, the awareness of these qualia would be much more difficult without representations.

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[1] William J.T. Mitchell, *Iconology: Images, Text, Ideology* (Chicago: University of Chicago Press, 1986); W.J.T. Mitchell, *Picture theory: Essays on Verbal and Visual Representation* (Chicago: University of Chicago Press, 1994); Gottfried Boehm, *Wie Bilder Sinn erzeugen* (Berlin: Berlin University Press, 2007).

[2] The pictures in Wittgenstein's theory are logical forms into which the states of affairs of the real world are projected. A pictorial form (*Form der Abbildung*) of a proposition serves as the main means for the expression of thoughts. See Ludwig Wittgenstein, *Tractatus Logico-Philosophicus,* trans. David Pears and Brian McGuinness (London: Routledge, 1961).

[3] Horst Bredekamp describes this capacity under the category of “image-act.” See Horst Bredekamp, *Theorie des Bildacts* (Berlin: Suhrkamp Verlag, 2010).

[4] Sybille Kraemer, ‘Operative Bildlichkeit. Von der ‘Grammatologie’ zu einer ‘Diagrammatologie’? Reflexionen über erkennendes Sehen’, in *Logik des Bildlichen. Zur Kritik der ikonischen Vernunft,* ed. Martina Hessler and Dieter Mersch (Bielefeld: transcript 2009), 94-123.

[5] Stephen Kosslyn, *Image and Brain: The Resolution of the Imagery Debate* (Cambridge, MA: MIT Press, 1994).

[6] Anna Munster, *Materializing New Media*: *Embodiment in Information Aesthetics* (Hanover: Dartmouth, 2006).

[7] Mark B.N. Hansen, *Bodies in Code: Interfaces with Digital Media* (London, New York: Routledge, 2006), 93.

[8] Mark B.N. Hansen, *Feed Forward: On the Future of Twenty-First Century Media* (Chicago: University of Chicago Press, 2015), 197.

[9] Jan Slaby, “Steps towards a critical neuroscience,” *Phenomenology and the Cognitive Sciences* 9 **(**2010): 397-416; Joseph Dumit, *Picturing personhood: Brain scans and Biomedical Identity* (Princeton: Princeton University Press, 2004).

[10] Jan De Vos, "The Iconographic Brain: A critical philosophical inquiry into (the resistance of) the image," *Frontiers in Human Neuroscience* 8 (2014): 300.
[11] Anne Beaulieu, "Images are not the (only) truth: Brain mapping, visual knowledge, and iconoclasm," *Science, Technology & Human Values* 27 (2002): 53-86.
[12] Lorraine Daston and Peter Galison, *Objectivity* (Cambridge MA: The MIT Press, 2007).
[13] Colin Milburn, *Nanovision: Engineering the Future* (Durham: Duke University Press, 2008), 13.
[14] Ibid., 14.
[15] John Johnston, "Machinic Vision," *Critical Inquiry* 33 (1999): 27.
[16] As Lisa Cartwright describes, the machinic logic of vision (e.g. cinematic, as in the late 19 century) employed in physiological experiments is inscribed directly onto the bodies of experimental subjects, serving as "a disciplinary technique, insofar as it facilitate[s] the establishment of a productive dynamic economy of the body." Lisa Cartwright, *Screening the Body: Tracing Medicine's Visual Culture* (Minneapolis: University of Minnesota, 1995), 37.
[17] http://gallantlab.org/index.php. See also Klein et al., "Retinoptic Organization of Visual Mental Images as Revealed by Functional Magnetic Resonance Imaging," *Cognitive Brain Research* 22 (2004), 26-31.
[18] Ivan Martinovic, Doug Davies, and Mario Frank, "On the feasibility of side-channel attacks with brain-computer interfaces," in *Proceedings of the 21st USENIX Security Symposium* (2012).
[19] Cortland J. Dahl, Richard J. Davidson, and Antoine. Lutz, "Reconstructing and deconstructing the self: cognitive mechanisms in meditation practice," *Trends in Cognitive Science* 19, no. 9 (2015): 515-523. 10.1016/j.tics.2015.07.001, referenced in Hannes Bend, Shawn Slater, Benjamin Knapp and Nuo Ma, Robert Alexander, Bella Shah, Ryan Jayne, "Mindful Technologies Research and Developments in Science and Art," in *Proceedings of Association for the Advancement of Artificial Intelligence* (2016), 330 available at: http://www.aaai.org/ocs/index.php/SSS/SSS16/paper/download/12765/11973.
[20] Michael Posner, Yi-Yuan Tang, and Gary Lynch, "Mechanisms of white matter change induced by meditation training," *Frontiers of Psychology* 5, 1220 (2014).
[21] Bach-y-Rita's research in sensory substitution and neuroplasticity led to the BrainPort technology that allows a blind person received images bypassing the optic nerve through electro-tactile stimulation of tongue receptors. See Paul Bach-y-Rita, Carter Collins, et. al., "Vision Substitution by Tactile Image Projection," *Nature* 221 (1969): 963–964.
[22] Paul Bach-y-Rita, "Sensory Substitution and Qualia," in *Vision and Mind: Selected Readings in the Philosophy of Perception*, eds. Alva Noë and Evan Thompson (Cambridge, MA: MIT Press, 2002), 500.
[23] Jillian Scott and Esther Stöckli, *Neuromedia: Art and Neuroscience Research* (Berlin, Heidelberg: Springer, 2012), 104-110.