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The Body as Musical Instrument

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Abstract and Keywords

This chapter explores the possibility of thinking of the human body as musical instrument. It builds on the philosophy of phenomenology to discuss body schemata that might be considered "instrumental" and discusses the diversity of bodies proposed by body theory to consider the incorporation of digital technology. Concepts of embodied interaction from the scientific field of human–computer interaction are discussed with an eye toward musical application. The history of gestural musical instruments is presented, from the Theremin to instruments from the STEIM studio. The text then focuses on the use of physiological signals to create music, from historical works of Lucier and Rosenboom to recent performances by the authors. The body as musical instrument is discussed in a dynamic of coadaptation between performer and instrument in different configurations of body and technology.

Keywords: digital musical instrument, EEG, EMG, MMG, musical gesture, embodied interaction

Introduction

Musical instrument performance solicits the human body into interaction with an acoustic, sound-producing object: the instrument. This engages the performer in forms of corporeal interplay not just with the instrument but also with the music being played, the resulting physical sound, and the space in which it is manifest. More than just a manipulation of mechanical aspects of an instrument—pressing keys, closing holes, or exciting strings—this interaction takes on a visceral dimension. Brass instruments, for example, offer acoustic resistance back to the player's lips, helping them with intonation. This interlocking of acoustic and body physiology takes on a phenomenological dimension and can be thought of as a cybernetic human-machine extended system. The idea of an extended system goes beyond any architecture of technology and becomes a set of McLuhan-esque “extensions,” where the medium and characteristics of the medium—in this case sound—affects us (McLuhan 1964).

Technologies of whole-body interaction today are widespread beyond music. Game controllers use cameras and sophisticated computer-vision technology to detect user movement for gameplay. Mobile phones are equipped with inertial sensors that detect rotation and orientation in three-dimensional space, allowing tilting motions to scroll through lists and other forms of interaction without touching the screen. These devices, and the sensors in them, have been used by artists and musician to create new musical instruments (Jensenius and Lyons 2016). But despite the embodied interaction that these digital technologies allow, do they create the same, tight corporeal coupling that we observe with the trumpet player?

Physiological sensors internalize the otherwise exterior nature of movement detection by directly sensing signals from the human body. Rather than external sensors (such as gyroscopes) reporting on the results of bodily gesticulation, biosensors are electrodes placed directly on the body that report on the corporeal activity at the source of body movement. Originally used in analytical contexts in the biomedical field to study muscle development, atrophy, or gait, they are increasingly used in interactive contexts to aid in stroke rehabilitation or even allow prosthetic limb control. The digitization and miniaturization of these technologies have allowed them to come out of the medical laboratory to be used in everyday contexts, including going on stage to be used in musical performances. Could these technologies of physiological sensing afford a connection between performer and digital music system that recalls the visceral acoustic coupling between performer and acoustic instrument? If so, can we imagine configurations of such technologies that would allow the body itself to be thought of as a musical instrument?

This chapter presents the history of embodied interaction in music, leading up to physiological sensing in contemporary experimental musical practice. It draws on theories of the body and philosophies of phenomenology (Merleau-Ponty 1962) in proposing body schemata that might be considered “instrumental.” This prompts a definition of “instrument,” musical and otherwise. It also demands an examination of our relationship to technology in order to understand what part of the human-machine interface becomes instrumental. Concepts of technological embodiment in cultural studies of the body (Hayles 1999; Haraway 1985) and embodied interaction in the scientific field of human–computer interaction (Dourish 2004) are thus considered to provide a cross-disciplinary view on the issue. The chapter ends by proposing two further notions drawing on musical performance: coadaptation (Mackay 2000), where the system learns the user while the performer learns the system; and configuration (Donnarumma 2012), where the capacity of the instrument and the performer are interlinked and thus mutually affect each other.

Proprioception

Proprioception is the mechanism that allows the body to determine the position of neighboring parts of the body and the effort exerted to perform a physical gesture. Schmidt and Lee (1988) describe how this is made possible by the integration of information from a broad range of sensory receptors located in the muscles, joints, and the inner ear. Proprioception is situated between two other modes of self-perception described by Merleau-Ponty: exteroception and interoception. Exteroception organizes tactile sensitivity to external objects, whereas interoception organizes the sensitivity to the movement of the body's internal organs.

According to Merleau-Ponty, "there is not a perception followed by a movement, for both form a system which varies as a whole" (1962, 111). Perception and movement function together, constituting a delicate balance between intention and performance, between the movement as intended and as it actually occurs. Proprioception can be thought of as a kind of closed-loop motor control mechanism, where the body uses the senses to compare the desired movement to the performed motion, assessing a margin of difference. This information aids in calibrating continuous movement, and establishes forms of feedback where action and perception continuously complement one another.

For Merleau-Ponty, proprioception can be both conscious and preconscious. An example of conscious proprioceptive mechanism is the case where one touches the tip of the nose with the eyes closed. In this case, one does not learn the position of the nose through sight, but it is the sense of proprioception that provides this information. On the other hand, preconscious proprioception is demonstrated by a "righting" reflex, an involuntary reaction that the human body produces to correct body orientation when falling or tripping. For instance, when one falls asleep while sitting on a train, the head repeatedly tends to fall on one side and the body moves the neck muscles autonomously to correct the head position. These two modes of proprioception show that "the body and consciousness are not mutually limiting, they can only be parallel" (1962, 124).

Playing musical instruments at first glance would seem to be a clear example of exteroception. However, the masterful playing of an instrument requires more than the tactile sensitivity for manipulating the mechanics of an instrument as object. The parts of the body that are not in direct contact with the instrument, and their position and movement, can be as crucial (if not more) to tone quality and expressive musical phrasing as the body parts that actuate the mechanics of the instrument. Control of the diaphragm is fundamental in wind instrument performance and has a direct effect on the sound quality achieved by the performer, and can also lead to extended technique such as circular breathing. This can be thought of as a case where interoception becomes an important part of musical instrument performance. Elbow position of the bowing arm on a stringed instrument is fundamental not just for producing good tone but also for avoiding physical injuries such as carpal tunnel syndrome. This requires a sense of proprioception for the instrumentalist to be aware of and adjust the location of limb joints in free space.

With practice, these techniques for musical instrument performance become increasingly fluid and intuitive for the performer. Can we think of these as conscious processes that, through repetition, enter the preconscious of the musician? If technologies of physiological interaction might allow the body, in the absence of a physical object, to become itself the musical instrument, exteroception may disappear completely, leaving interoception and proprioception as direct conduits to electronic sound production.

Body Schemata

To further understand the superposition of conscious and preconscious factors determining human movement in musical instrument performance, it is worthwhile to look at the notion of body schemata. These are schemes used by the body to govern posture, movement, and the use of physical implements. Body schemata can be thought of as motor control programs. Merleau-Ponty gives an example by observing the case of a blind man's white cane. For Merleau-Ponty, the stick is not an external object to the person who carries it, but rather, for its owner the stick is a physical extension of touch. The stick becomes an additional source of information on the position of the limbs, so with continuous training it becomes integrated into the body schema. It is converted into a sensitive part of the body, or extends the senses, and becomes part of the blind person's proprioceptive sense and motor programs.

Interestingly, Merleau-Ponty (1962, 145–146) also gives the example of musical instrument performers, describing the case of the organist. When rehearsing for a performance with a new organ, the organist, according to Merleau-Ponty, does not commit to memory the objective position of pedals, pulls, and stops. Rather, she incorporates the way in which given articulations of pedals, pulls, and stops let her achieve given musical or emotional values. Her gestures draw “affective vectors” mediating the expressiveness of the organ through her body. The organist does not perform in an objective space, but rather in an affective one. Body schemata constitute “knowledge in the hands,” in the words of Merleau-Ponty. This form of corporeal epistemology is the basis of “enactive knowledge” proposed by both the psychologist Jerome Bruner (1968) and the scientist Francisco Varela (Varela, Thompson, and Rosch 1992).

In musical performance, body schemata drive the way the performer physically interacts with the instrument in accord with the musical or affective expression that the instrument affords. The instrument goes beyond the blind person's stick in the sense that it is more than an extension of perception. It also goes beyond the intuitive sense Merleau-Ponty's organist has in moving between different organs of different dimensions. A musical instrument invokes body schemata in ways that extend the human body's expressive potential in the projection of sound. The instrument becomes an extension in the sense of McLuhan, where a medium, or technology, shapes the relationship between us and the world in which we live. Can we, with electronic musical instruments, go beyond the affective dimension Merleau-Ponty describes in the organist? If physiological sensing technologies extend the sonic expressive potential of the performer's body directly without an intervening stick or organ, where does the enactive knowledge reside? In the sound itself?

The Technological Body

Body theory provides one lens, through a cultural analysis of the body. By going beyond Cartesian mind-body dualism to regard the body not just in its physiological manifestation, theories of the body accommodate a plurality of bodies—bodies that can be natural, social, material, or immaterial (Blackman 2008). Part of the diversity of potential bodies is as an entity enmeshed with technology. Haraway (1985) and Hayles (1999) provide interwoven definitions of what it means to be human in the increasingly intimate relations between humans and “machinic” or computational technologies, with Hayles proposing the notion of the posthuman body. Haraway analyzes the notion of the cyborg—a cybernetic organism part human and part machine—in contemporary science fiction and modern medicine (1991). In her view, the cyborg blurs the humanist models of a unitary gender, species, or human nature by placing humans, living beings, and machines on the same ontological ground. Haraway conceives of living (human, animals, plants) and nonliving beings (machinic and computational technologies) as unbounded entities or cross-species characterized by a blurring of boundaries. From there, it follows that the body is not bounded by a membrane such as skin (the dermis) but that human and nonhuman bodies meld continuously—they are “taken apart and put together” in the realization of hybrid living entities.

Hayles’s reading of the posthuman is based on a twofold premise of the meaning of embodiment. On one hand, embodiment signifies the material instantiation of an organism in a given context; on the other, it signifies the information pattern that an organism yields (1999, 2). In this view, both human being and computer code can be considered to be embodied. They are both situated—their existence is meaningful in a specific context, be it a city or a computer, and they yield and share information patterns. For Hayles, human beings and machines share information patterns through their interaction, and in so doing, they constitute each other’s modalities of embodiment.

The posthuman discourse posits that technologies can be seen not simply as extending the body, but as hybridizing with it. This can be achieved at a number of different levels: through mediating interfaces, or directly though biomedical technologies. Technologies of human–machine interaction digitally mediate relationships between the body and the surrounding environment. The advancement of biomedical technologies has facilitated the development of physiological interfaces, making this link more direct with the lower level functions of the human body. This has captured the imagination of musicians, from making electronic musical instruments that capture the spatial perturbation of human movement to detecting lower level bodily function as a musical source—perhaps coming closest to the sense of body as instrument.

Embodied Interaction

If the broad deployment of new human interface devices (including the computer mouse) represented the development of computer–human interaction in the 1980s, the development of interfaces like gloves and motion capture systems in the 1990s brought interest in whole body and embodied interaction. The exponential increase in processing speed, and the possibility to render digital media in (or faster than) real time, changed not only the forms of interaction possible with computing machines but also the contexts in which they were used.

Embodied interaction, for Dourish (2004), is one in which computers go beyond metaphorical, representational connections to the physical world, but begin to function in ways that draw on how we as humans experience the everyday world. Embodiment seen from this perspective is not just corporeal but also reflects states of participation in the wider world. This parallels, perhaps, the expansive conception of the body we noted in the previous section. In outlining the challenges of embodied human–computer interaction, Dourish draws on philosophies of phenomenology, of Heidegger and Merleau-Ponty, again questioning Cartesian mind/body dualism. He uses a phenomenological framework to look at examples of ubiquitous, tangible, and social computing, offering a theoretically informed analysis of the otherwise technologically deterministic development of the technologies that now constitute the digital nature of contemporary life.

Dourish evokes Heidegger's term of "Being in the world" as a nondualistic way to think about our interaction with digital technology. He starts with the simple notion of familiarity and the tendency of tangible and social computing to exploit familiar real-world situations and metaphors to set the scene for his definition of embodied interaction. If we inhabit our bodies, which in turn inhabit the world around us, then computing systems, for Dourish, should not just present metaphors for interaction but also become mediums of interaction. He continues, by drawing on Heidegger's notions of *zuhanden* and *vorhanden* ("ready to hand" and "present at hand"), to think about the transparency of computer interfaces, and considers whether they were the object of attention, or a medium facilitating another action. If a computer interface, such as a mouse, becomes the object of our attention in an activity, it is *vorhanden* (present at hand). If, on the other hand, the device itself becomes transparent, and we act through the device as an extension (in the McLuhan-esque sense) of our body in realizing an action, it is *zuhanden* (ready to hand).

The application of Heidegger's concepts to human–machine interaction is potentially fruitful when extended to music and embodied interaction with musical instruments, be they technological or not. Learning a musical instrument (or any new piece on an instrument) typically requires an investment of time, and concentration on its mechanics, posture, and fingerings. This can be thought of as *vorhanden*—focus on the object. After mastery of an instrument or with increasing confidence in a particular piece, accomplished performers describe “speaking” through the instrument, where they become just the vehicle through which the music speaks. These situations, we claim, are the transfer of instrument as interface from *vorhanden* to *zuhanden*. Is this the affective sense of Merleau-Ponty’s organist? Could this be a useful way to consider the potential of physiological sensing technologies to turn the human body itself into an instrument?

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Figure 1 Clara Rockmore performing on the Theremin in the 1930s.

The Body In Electronic Music

Despite the potential of electronic media providing extensions to the human capability for producing music, electronic and computer music, at first glance, have traditionally not implicated the human body in visceral ways. Large recording studios and modular electronic music synthesizers full of racks interconnected by patch cables are not portable in ways that we assume musical instruments need to be. Computer music programming languages, despite recent movements such as “live coding,” were not originally conceived for physical performance. We tend to think of these technologies of music production, be they analogue or digital, as disembodied technologies. However, Hayles’s notion of sharing information patterns indicates that things may not be so simple. Indeed, the broad assumption that digital tools for music production are disembodied is immediately proven false in uncovering the history of gestural and embodied electronic music.

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Figure 2 Michel Waisvisz performing on The Hands in the 1980s.

Michel Waisvisz Archive.

One of the earliest, and most iconic, instruments in the history of electronic music is gestural. The Theremin (Figure 1), invented by the Russian scientist Lev Termen (Leon Theremin) in 1920, used two antennas and electrical circuitry converting electric field perturbations into musical tones to create an electronic musical instrument that was played by waving the two hands. Similar instruments, such as the Ondes Martenot and the Trautonium, were also invented in the early twentieth century (Hopkin 1997). This approach to detecting performer gesture for live electronic performance continued in the 1980s. Michel Waisvisz conceived of the instrument, The Hands (Figure 2), and other similar instruments at the Studio for Electro-Instrumental Music (STEIM) in Amsterdam. In 1991 Laetitia Sonami combined early glove-based technologies from first-generation virtual reality and early video gaming with domestic utility and fashion imagery to build a series of instruments called the *lady's glove* (Figure 3). Both The Hands and the *lady's glove* predated consumer electronics equipped with motion capture and used custom sensor electronics to transform performer movements into Musical Instrument Digital Interface (MIDI) data, allowing the performer on stage to articulate and sculpt electronic and digital sound synthesis (Krefeld and Waisvisz 1990).

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Figure 3 Laetitia Sonami performing on the Lady's Glove in the 1990s.

This early work has spawned communities of practice in the area of new instrument building, or digital musical instruments (DMIs). The research area that encapsulates these practices is the field of new interfaces for musical expression (NIME), where interactive technologies are used to build electronic music devices that could be performed live, through gestural interaction, in an instrumental manner. However, for the most part, the instruments produced are, like traditional instruments, external objects for the performer to hold and manipulate—instruments through which music is performed.

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Figure 4 Alvin Lucier preparing (aided by John Cage) for "Music for Solo Performer" in 1988 at Wesleyan University.

Photo by N. Walz.

In 1965, the composer Alvin Lucier met the scientist Edmond Dewan, who was conducting research on electroencephalogram (EEG) signals in relation to aircraft pilots' epileptic fits. Using hospital electrodes on a headband and analog circuitry to amplify alpha waves resulting from relaxed, meditative states, Lucier created a seminal work of biomusic, "Music for Solo Performer" (Figure 4). In the piece, the performer sits center stage wearing sensors around the head. The output of the brainwave amplification circuits drives loudspeakers connected to percussion instruments, exciting them and causing them to sound, following the alpha rhythm (8–13 Hz) of the brainwave production of the performer. Around the same time, David Rosenboom, in the early 1970s, also worked with brainwaves, in his case, connecting the signal from the brain into the signal path of an analog modular synthesizer (Rosenboom 1976) (Figure 5).

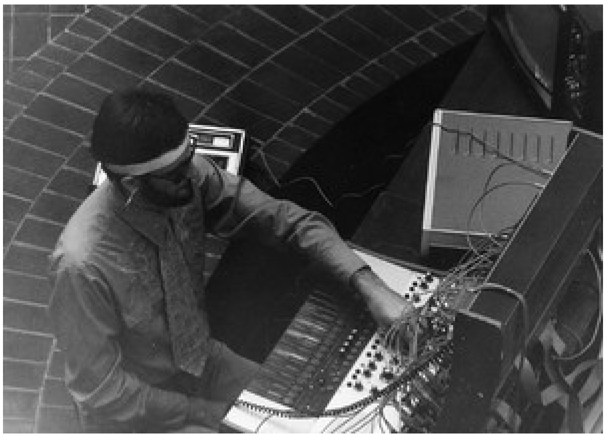

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Figure 5 David Rosenboom performing "On Being Invisible" in 1978 in Mexico City.

Archives of D. Rosenboom.

Did these works and experiments turn the human body into a musical instrument? Or did they begin to explore other experiential notions for the performance of music that did not depend on volitional acts of an instrumentalist?

Digital Biosignal Interfaces for Music

The miniaturization of transistor electronics in integrated circuits along with the increasing practicality of analog-digital conversion and availability of digital signal processors such as the Motorola 56000 brought about a step change in physiological interface development in the late 1980s and early 1990s. While the facility of prototyping speed and convenience did not match the ease of present-day platforms like the Arduino, or the flexibility of programmable microcontrollers, advances in electronics did allow engineers and small companies to create custom, digital biosignal interfaces for the arts.

The adoption of MIDI as a communications bus for synthesizers provided a standard for intercommunication between musical devices, and a data format for the representation of performer actions—discrete actions in the form of note on/off messages, and gestures in the form of continuous controller messages. Early digital biosignal interfaces for the arts included the BioMuse, the BodySynth, and the IBVA. The BioMuse was created by Ben Knapp and Hugh Lusted, researchers at Stanford University's Center for Computer Research in Music and Acoustics (CCRMA), and was first shown publicly in 1990. It was a digital-signal processing (DSP) based biosignal-MIDI interface that read biosignals from the heart (EEG), eyes (electro-oculogram, or EOG), and muscle (electro-myogram, or EMG) to output MIDI based on user definable mappings (Lusted and Knapp 1988). The BodySynth, created in 1991 by Chris Van Raalte and Ed Severinghaus was an EMG music interface used by performance artists such as Pamela Z and Laurie Anderson. The Interactive Brainwave Visual Analyzer (IBVA, 1991) was created by Masahiro Kahata and was an early low-cost, portable digital EEG device for art. More recently, in order to provide an alternative to the MIDI gestural interfaces described already, Donnarumma has created the open-source instrument XTH Sense (2011). This detects mechanomyogram (MMG) signals through a compression cylinder and microphone, allowing biosignals to interface with computer systems through audio interfaces.

With the exception of the last example, these devices can be contextualized in the era from which they came—early digital technologies, MIDI-based control paradigms in electronic music, first-generation virtual reality, and human–machine interface research. Interest in new interfaces for computing accompanied the early success of the Apple Macintosh and the mouse in 1984. While the computer mouse had been invented in 1964 and had been used in specialist systems in the 1970s, it was its mass appeal and ease of use in a personal computer that captured the public imagination for new, engaging forms of interaction. The late eighties was also the first wave of virtual reality technology, and included peripherals like head-mounted displays and glove-based interfaces. There was an interest in all things virtual, with interfaces allowing the user to navigate these parallel, digital "realities." In this spirit, biosensor musical interfaces became the basis for possible "virtual instruments." In this case, the question was not whether the body itself became instrument, but whether, thanks to sophisticated human interface technology, it allowed the musician to create virtual instruments that were immaterial and purely digital.

The human–machine interface paradigm in this time categorized computer peripherals as input devices or output devices. The former were the keyboards and mouses, and the latter screens, speakers, and printers. Following this paradigm, these musical interfaces were input devices—interfaces meant to capture human action to translate as an input to command a computer system. The conception of MIDI as a protocol for music also paralleled this control paradigm, in a master/slave configuration. Seen from this perspective, new interfaces for music were thought of as controllers with which to dictate digital sound production by way of human action. We explore in what follows how this controller paradigm has evolved and changed in the time since.

Recent Performance Practice

In this section, we describe three works by the authors that parallel this evolution. They respond not just to developments in technology, but demonstrate conceptual shifts in the relation of the performer's body and technology in musical performance practice.

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Figure 6 Atau Tanaka performing *Kagami* on the BioMuse in 1993 at _V2, Rotterdam.

Photo by J. Sprij.

Kagami ("Mirror" in Japanese) was the first concert piece for BioMuse, composed and performed in 1991 by Atau Tanaka (see Tanaka 1993) (Figure 6). It used two channels of electromyogram (EMG—a stochastic series of electrical pulses resulting from neuron spiking), one on each forearm to track muscle tension of the performer. The BioMuse performed envelope following on the raw EMG signal and translated muscle tension intensity to continuous MIDI controller values. This transformed the performer's body into a MIDI instrument to control digital synthesizers. Instead of the dials, faders, and ribbons that typically generated MIDI continuous control data, the BioMuse captured concentrated, free space arm gesture. The MIDI data reflecting muscle tension of the performer was mapped to different parameters of frequency modulation (FM) and waveshaping vector (WS) sound synthesis on Yamaha and Korg synthesizers. A score, in the form of interactive software, ran on an onstage computer. The software determined the mapping assignment as well as ranges—specifying which synthesis parameter would be controlled by which muscle and how the MIDI control values, ranging from 0 to 127, would be mapped to salient musical values. Oscillator values might be specified as frequency in hertz or in MIDI values for diatonic notes. Modulation and waveshaping indexes would operate on a different set of ranges. In addition to defining controller mappings, the score software set the structure of the piece—the sequence of mappings that would be performed by the musician. Rather than imposing a fixed timeline, each section of the piece was invoked by combinations of muscle gestures. The score would set muscle tension thresholds as triggers. Certain combinations of triggering across the two arms (one followed by another in time, or the two simultaneously) would trip the triggers, advancing the composition to the next section, setting parameters and sequences of melodies which would then be sculpted by the mapped controller data. Building on the idea of sound as mirror for the body, and drawing on the Japanese reference in the title, the sounds of the piece used synthetic approximations of evocative sounds, starting with low throat-singing voices, punctuated by *taiko* drums, leading to rapid melodies of bell tones, finishing with siren-like breaths and *odaiko* percussion.

Ominous (2013) is a sound sculpture generated and manipulated live by a performer. In this piece, created by Marco Donnarumma, music is produced in real-time using the mechanomyogram (MMG, acoustic vibrations emitted by muscular tissue). A computer program digitizes the raw signals in the form of audio input and makes it available for live sampling. The piece is based on the metaphor of an invisible object in the player's hands that is made of malleable sonic matter. Similar to a mime, the player models the object in empty space by means of whole-body gestures. A column of red light illuminates the performer's hands. The muscle sounds produced by the contractions of the performer's muscles are amplified, digitally processed, and played back through a circular array of eight subwoofers and eight loudspeakers. The MMG signal of the left bicep flows through a four-stage digital signal processing (DSP) system, whose parameters are driven by synced contractions of the right forearm muscle, with each DSP stage sending its resulting signal to one of the loudspeakers. This creates a multilayered sound where disparate sonic forms can be precisely shaped by coordinating and fine-tuning whole-body gestures that address one or more DSP stages at once. The interplay between instrument and performer relies not only on the MMG sonification but also on strategies of interaction that include extracting expressive features from the muscle sounds, mapping dynamically those features to DSP parameters, and composing the piece sections in real time using neural networks. The MMG sensors on the forearms are analyzed for high-level features, such as abruptness, subtleness, or rhythm of the player's movement. According to these features, the muscle sounds are digitally processed, played back, and spatialized. A neural network compares the stream of muscle sound features with patterns it has learned offline, detects the player's current muscular state, and subsequently loads a new set of mappings and activates or deactivates specific DSP chains, effectively changing the gesture mapping definitions throughout the performance based on the performer's dynamics. Together, the natural muscle sounds and their digital and virtual extensions blend together into an unstable sonic object. As the listeners imagine the object's shape by following the performer's physical gestures molding the red light, a kind of perceptual coupling enables listeners to hear and feel a sculpture that cannot be seen (Figure 7).

Click to view larger

Figure 7 Marco Donnarumma performing *Ominous* on the XTH Sense in 2015 at CTM, Berlin.

Photo by S. Kulisch.

Myogram (2015) is a recent EMG work by Tanaka, and uses a commercially available EMG interface. Two such devices (one on each forearm) each report 8 channels of EMG, providing 16 total channels across the two arms, giving a relatively detailed differentiation of muscle groups around the forearms that are invoked in manual gestures such as wrist rotation, hand flicking, and finger movement. In *Myogram*, the raw EMG data is heard through a process of direct sonification, making musical material out of the corporeal signal where electricity generated by the body provides the sounds heard in the work. The signals from pairs of EMG channels are routed to an individual speaker in an octaphonic sound system. The sensors reporting muscle tension on the ring of muscles on the left arm are heard on four speakers in the corners of the wall, stage left, from the front to house to back of the concert hall, from below stage up to the ceiling. Likewise, the eight EMG channels on the right arm are routed to four speakers in the corners of the wall, stage right. By making rotating gestures of the wrists, the muscles in the perimeter of the forearm are solicited in circular sequence. This is heard in the concert hall as spatial sound trajectories of neuron spikes projected in the height and depth of the space, with lateral space divided in the symmetry of the body. Through the composition of the work, these raw physiological signals are subjected to different signal processing treatments. Low pass filters (LPFs) first tune the contour of the sound to de-emphasize the high-frequency transients of the neuron spikes to focus on the stochastic low-frequency fundamental. Ring modulators allow sum and difference frequencies of the EMG data relative to reference frequencies to be heard. Resonators set up resonant filters tuned to specific frequencies, which are excited by the EMG data. Frequency shifters transpose the raw muscle signal data by musical intervals. The performer responds to these different sonic contexts for the sound generated by his own body by gesticulating in space to create physiological signal output that “plays” the space, the filters, and resonators.

Control, Coadaptation, and Configuration

This range of work, from the historical works of the analogue era in the 1960s to today’s digital era, demonstrates our changing relationships to technology, notions of the interface, and ultimately evolving visions of the body. The early work of Lucier and Rosenboom sought to track the performer’s state and reflect that in the music. By tracking involuntary action, they focused on forms of biofeedback, reflecting the spirit of the sixties era in which these works were conceived. Other works from the time that exemplify this spirit include John Cage’s *Variations VII*, performed at Experiments in Art and Technology (E.A.T.)’s seminal 9 Evenings series in 1966. In this piece, Cage created a large-scale work of an environment of multiple sound sources—live telephone lines of the city, radio, and space signal receivers, for performers to “tune in.” This list of sound sources includes what Cage described as “Body” to join the sonification of communication waves and urban activity. David Tudor’s *Rain Forest* (1968), while not explicitly using body signals, perhaps demonstrates the environmental links imagined at the time between technology and the surrounding world. In *Rain Forest*, sound transformations, of the sort inspired by electronic music, were realized without the use of electronics and instead by transmitting sound sources through resonant physical materials. Both look at forms of indeterminacy as a way of “being in the world.”

In contrast, the work of the 1990s reflects the human-interface era. At that time, significant advancements were made in computer science in the elaboration of novel input devices. This zeitgeist influenced the development of DMIs of that era, many of which were conceived of as new musical controllers. Bio-interfaces, including the BioMuse and Bodysynth, were thus conceived of as control inputs to a computer music system, designed to allow a performer to control musical output through corporeal activity. There is a shift in paradigm, from biofeedback in the 1960s to biocontrol in the 1990s. *Kagami*, as described earlier, represents this era. In this regard, the proposition of body-as-instrument in this work plays into a technicity of electronic music, afforded by the MIDI communications protocol, of networking and interoperation of synthesizers. The MIDI specification was conceived on a master/slave model, where the default master controller imagined was a piano keyboard. The MIDI controllers built on other instrumental metaphors, such as woodwind or guitar controllers, were dubbed “alternate controllers.” The BioMuse, as physiological MIDI device, proposed the body as MIDI controller, ostensibly with the richness of biosignals opening up new possibilities for synthesizer performance. While the concept body as instrument in this era sought to make these relationships more visceral and organic than the coldness of button presses and slider moves, it remained limited to a unidirectional control metaphor, one of first-order cybernetics (Wiener 1948).

Myogram moves away from control to a form of coadaption between body and sensitive system. The system in its transparency allows the body in its pure state to be heard. By filling the concert space with sound in abstracted morphogenic dimensions—the left and right walls reflecting the two halves of the body, respectively—the gestures of the performer enter into interaction with the space of the concert hall. This creates a coadaptation of instrument and performance venue in spatial terms, amplifying the topology of the body, but also creating a direct interaction between the performer's body and the acoustic space shared with the audience. The system becomes less transparent as the piece progresses, taking on resonant characteristics. To play these resonances musically, the performer must find the best gestures to enter into resonance—the "wrong" gesture might create excessive feedback or not excite the system at all, depending on the propagation of sound waves in the specific dimensions of the hall. By playing the space, and the interactive signal processing system, the body as instrument is extended to integrate the acoustic space inhabited by both performer and audience.

In *Ominous*, the continuous changes of the player's physiological state and the way in which the instrument reacts to those changes are both crucial to the performance. It is a relationship of *configuration*, where specific properties of the performer's body and those of the instrument are interlaced, reciprocally affecting one another. The gesture vocabulary, sound processing, time structure, and composition are progressively shaped, live, through the performer's effort in mediating physiological processes and the instrument's reactions to, and influence on, that mediation. The unpredictability of this relationship makes the performance both playful and challenging. The music being played is not digitally generated by the instrument nor fully controlled by the performer. Instead, the music results from the amplification and live sampling of the player's bodily sounds. As a performance strategy, it blurs the notion of control by the player over the instrument, establishing a different relationship among them, one in which performer and instrument form a single technological body, articulated in sound and music. Here, an expanded definition of the body parallels the extended notion of the instrument.

Conclusions

This chapter presented the idea of the body as instrument as a notion relying on a multifaceted and cross-disciplinary set of resources, ranging from cultural studies of the body to human–computer interaction, from phenomenology to musical performance. The idea of the human body as musical instrument is shown to be a malleable idea changing across cultural contexts and technological advancements. The understanding of the body as instrument varies according to both the degree of technological intervention and the aesthetic concerns of individual artistic practices. The mechanisms of proprioception, the functioning of body schemata, and the broader understanding of the phenomenological basis of human embodiment, show the human body as inherently open to become, integrate, or combine with an instrument. Physiological technologies for musical performance hold a potential for the body to viscerally interact with machines. This creates interactions between the performer and system, performer and space, and performer and audience, as forms of musical expression that are embodied, adaptive, and emergent. This enables novel ways of exploring sound and space, linking sonic stimuli and spatial resonances with the physiological processes of a musician in performance.

From feedback to control, coadaptation to configuration, the potential for body as musical instrument has evolved in a half century of practice. These developments are technological and conceptual, and intertwined. The evolution reflects different levels of integration and fusion of body and technology, but the trajectory is not a linear one. The work of the sixties reflects an ideal of integration through feedback where the technology is “ready to hand,” or a transparent vehicle between body and environment. The interfaces of the nineties, though an intention to master technology, belie a greater distance between body and technology. The control interfaces are “present at hand,” objects focusing attention to carry out a musical task. The body as instrument is technical, cybernetic, and imbued in a musical culture of virtuosity. The recent work extends the boundaries of the body to include the concert space, and imagined editable configurations of body and semiautonomous signal processing. This reflects forms of second-order cybernetics (Glanville 2002), where an organismic view replaces system architecture, and where noise and positive feedback temper entropy. By proposing an expanded body that encompasses technology and space, these last examples respond to the possibility of the posthuman body, proposing hybridized bodies as instruments beyond the extent of the unitary corporeal body.

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