Body in Resonance

Expressing the Bodily Imprint

by

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Introduction

Electronic music equipment is historically deeply interwoven with developments in scientific and military fields, of which the primary goal of measurable progress has leaked into cultures of modern music (Holmes, 2012). Technological advancements have unquestionably impacted musical creation and understanding, but the underlying drive for precision and repeatability has led music technology to neglect the musical impulse. Instead, it becomes a pursuit of control over sound, offering users a select set of parameters with which to navigate through its structure.

For a musician working with digital electronics, this means there comes a point in the creative process where expression has to be quantified in order to enter a digital model. Composing interactions with software typically (and possibly inevitably) resorts to 'mapping' connections between controls from outside the system to functions in a code. This kind of software architecture creates a bounded, multiparametric space, in which every parameter is like an axis in the space.

By interacting with software, the programmer/musician reduces their musical impulse to a pre-defined set of signals that their code can accept. This reduction is not exclusive to software; it happens in musical notation and human language, too, and even human consciousness is a result of filtering chaotic stimuli to a limited set of 'useful' ones.

Digital technologies, in search of absolute measurements, disregard subjectivity and thus the role of the human body. Musical thought mediated through this framework loses its connection to the performing body; the musical impulse must be represented as a number so that it can enter the technological realm. What is lost in this situation is the potential influence the performer’s body has over the sound production. Bodily imprints – the unique reflections of a body in the sound it is producing – are pushed away in favor of generality and predictability.

The current thesis approaches this translation from a bodily perspective, to reconnect with the physical origin of the musical impulse and resist this reduction by symbolization. My methodology is rooted in bodily experience, rather than representation, to allow a music that is rooted in sensation, rather than analysis.

This thesis documents my theoretical and practical approach to involving my body in music. What started as a focus on physical effort in musical performance, developed into a more nuanced idea of the role of the body. The desire to somehow feel physically connected to sound, a connection I had with a piano but lost in a computer, inspired the idea of 'the body in resonance'. This slightly romantic idea places the body in a network with an instrument and its sound, with the aim to amplify bodily traces through this network. Resonance is more than just acoustic sympathy – the body in resonance is deeply engaged in physicality, while simultaneously appreciating its unique subjective perspective. "Resonance is affective knowledge that strongly informs how one "is" and what one knows" (Gershon 2013, 258). It is thus a way of recognizing the difference between experience and matter without placing more significance on one over the other.

An important part of this work is about the differences between physical, subjective, and digital understandings of sound. The human body and a digital system create fundamentally different impressions from acoustic vibration: the body gives rise to sensory experience and consciousness, while a digital system generates data. Without trying to give a concrete definition of sound, I aim to consider how these three forms of sound may come together. By using digital means to bring the physicality of sound to the sensory foreground, I attempt to bring the body in resonance.

Chapters 1 & 2 introduce the role of the body in giving rise to experience of sound and vibration, covering concepts of the bodily imprint and audio-tactility.

Chapters 3 & 4 describe and challenge the structure of 'the digital', and how it affects our understanding of sound. Transduction is discussed as a way of analyzing how a signal is affected when traversing media; giving the digital a body allows for transductions between physical and digital states.

Chapters 5 to 8 cover the practical applications of the current framework to instruments created over the course of the research. Technical details of the instruments are found in appendix A and B.

1. The Bodily Imprint

Listening For The Body

In the musical expression, a performer uses their body to act upon a structure of musical control. Moving their fingers, mouth, feet, or any other body part they feel necessary, they navigate the material mode of their instrument. Playing an instrument is thus an application of bodily understanding to the instrument's physical configuration. This is clear in acoustic instruments. Here, a performer's action is physically coupled to a sound-producing event, so that the force exerted by the body excites the acoustic structure. The expended energy is then transformed as it travels through the instrument's material properties, resulting in vibration. This acoustic vibration of material, the origin from which air pressure waves reach the performer's ears, is both audible and tactile. The necessity of using the body to excite the instrument thus allows the instrumentalist to physically feel the acoustic response of their actions. This tactility at the point of contact between performer and instrument is simultaneously action and perception – one can feel the material response of their action as they perform it, and use this perception to continuously adjust their action. The audible result of this situation is a materialization of the performer's musical impulse, mediated by their body and their instrument. The trace left by the performer's foundational role in this materialization I call the bodily imprint.

Sound carrying a bodily imprint essentially contains a reference to its manner of creation: a performer's body navigating the physicality of their instrument. The focus on the body as the location of the musical expression leads to a listening mode rooted in the physical world, rather than that of a detached 'sound object'. The bodily imprint is thus not necessarily an identification of an acoustic property in sound as much as it is an imposed projection of bodily understanding through the creative act of listening. By listening for the performer in the movement of sound, a listener may empathize with the movement of the instrumentalist. This is not unlike the neurobiological research in mirror neuron activity, in which certain parts of the human brain have been found to be active in both an action and in the perception of that same action, also described as "resonance behavior" (Rizzolatti et al 1999). John Cage described this "kinesthetic sympathy" as the "faculty we employ when, seeing the sight of birds, we ourselves, by identification, fly up, glide, and soar" (Cage 1961, 95). While he referred to dance, and the ability to sympathize with a moving body through vision, this can be extended to sound and listening. When the navigation of a performer's body through space shapes the resulting sound in time, a listener may attribute the sound's movement to the performing body's gestures. Marc Leman calls this the "sensorimotor basis of gestural communication" (Leman 2008, 21). He argues that the universal physical constraints of the human body allow a listener to draw meaning from the physical energies present in music. This type of listening for the bodily imprint happens through the body in its continuous 'making sense' of the world. Sound communicates the body because a listener knows what it means to have a body.

Bodily Understanding

Knowing 'what it means to have a body', in this situation, is a subconscious understanding gained from life in a body. The tight coupling of action and perception is so fundamental to life in a body that by force of habit one's awareness of it becomes subconscious; in most situations one is more aware of mental abstractions than of pure sensation (Levitin 2006). The world is experienced through simultaneous associations of sensorial perceptions made at incredible speed. The immediacy of using the body in instrumental navigation is thus rarely a completely conscious activity, but is enabled by this subconscious bodily knowledge.

Susanne Langer (1942) attributes intelligence to the sense organs: a subconscious understanding of stimuli entering the body that allows a person to derive abstracted forms (images, words) from pure sensation (sight, sound). She proposes that knowledge of the world originates in the body: "The conditions for rationality lie deep in our pure animal experience – in our power of perceiving, in the elementary functions of our eyes and ears and fingers" (Langer 1942, 71). What is notable here is Langer's recognition of the entire body as an information-processing system. From the moment an external stimulus reaches a sense-organ, the physical and material properties of the body are involved in 'making sense', creating forms and meanings that develop into knowledge and classification. With this, Langer places rationality, and by extension human being, in the body. The world is interpreted by the senses before it reaches the conscious mind, by way of deriving forms from sensation. Widening the scope of rationality to include pure perception means accepting the human body as a vehicle of knowledge.

Maurice Merleau-Ponty, too, places the body at the forefront of perception. He argues that all ‘making sense’ is affected by the body – he dismisses the duality of mind and a body, and argues that consciousness is mediated *through* the body. However, the body’s role in this mediation is to make itself invisible, causing subjective sensation to be interpreted objectively and dismissing the foundational function of the body. He argues that by reflecting upon the role of the body in constituting experience, one can reconnect with the self: “By thus remaking contact with the body and with the world, we shall also rediscover ourselves, since, perceiving as we do with our body, the body is a natural self and, as it were, the subject of perception”. (Meleau-Ponty 1945, 239). Like Langer, Merleau-Ponty encourages an appreciation for the senses and the body both in their pre-cognitive being and in their integral role for establishing consciousness.

Kinesthesia

The ‘kinesthetic sympathy’ Cage describes refers to the kinesthetic sense, fundamental to the relationship of body to world. Spread throughout the body in muscles, joints, and bones, kinesthesia allows one to feel how their body is positioned in space. Closely tied to tactility, vision, and balance, this full-body sense illustrates that the senses continuously (and subconsciously) affect one another in establishing bodily awareness (de Vignemont 2018). The kinesthetic sense, and that of balance, mostly acts in the ‘subconscious background’. A person may be so used to habitual movements or postures that they do not have to consciously think about which limb goes where. Certain practices like instrument playing, dance, or yoga challenge these kinesthetic habits: one can learn new movements by becoming aware of their body in space. The goal in practicing kinesthetic awareness can be said to embody one’s own body, in order to act upon the world.

Behind our skillful, intuitive control of our bodies lie intricate systems of perception and action that organize awareness, but in doing so are hidden from it. Describing these systems may reveal some physical processes underlying ‘sense’, but their pre-rational nature brings the inability to fully express them in words. Merleau-Ponty’s way of relating the body to external objects is facilitated by this wordless understanding: “A movement is learned when the body has understood it, that is, when it has incorporated it into its ‘world’, and to move one’s body is to aim at things through it; it is to allow oneself to respond to their call, which is made upon it independently of any representation" (Merleau-Ponty 1945, 161). Movements that are incorporated into the body's world become expressions of bodily understanding. When these movements form the basis of interaction with sound, they embed it with a bodily imprint.

2. Awareness

Bodily Transduction

In abstracting meaningful forms from chaotic sensation, the body acts as an intermediary that constitutes consciousness. Sensation is really an act of transduction[1], converting physical world to subjective experience as a stimulus follows a path from the sense organ to the conscious mind. In converting a signal between media, the process of transduction carries it into proportionate, or analogous, forms – a sound's acoustic qualities and its subjective perception are two forms of the same signal. The entire trajectory of a sound 'signal' from acoustic event to conscious sonic awareness can be seen as a chain of transductive events. The signal travels from material vibration at its source through various channels until it is registered in perception as a 'sound' (Levitin 2006). These channels, by their particular manner of working in the ear and sensory nervous system, introduce material and perceptual thresholds that shape the experience of sound.

Thresholds, towards Consciousness

Material Thresholds

Material thresholds are the conversions determined by the senses' physical capabilities of receiving information: the mechanics of the sense organs and the biochemical processes of the sensory nervous system affect the particular sensation of stimuli. In the ear, incoming vibrating air is mechanically converted in roughly three stages. First, the particular shape of the outer ear boosts frequencies around 3 kHz, (favorable for recognizing human speech) and the resulting air pressure excites the tympanic membrane, causing it to vibrate. Then, the signal is amplified in the middle ear through the transmission of the signal from the relatively large surface of the tympanic membrane, through the ossicles, to the 18 times smaller surface area of the oval window. This controls the dynamic range of incoming signal. Finally, the fluid in the inner ear receives the amplified vibrations from the oval window, and hair cells cause an electrical impulse based on the frequency of the sound – in humans only possible between 20 Hz and 20 kHz. The material thresholds of the ear thus affect the

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[1] Transduction is applied here as relating to the body, and described further in chapter 4.

[2] (While not all were used in staged performance, the word 'instrument' is used here

conversion of the signal, from acoustic air pressure to thousands of electrical signals, by filtering it in dynamic and frequency range.

The electrical signal is then transported through the auditory nerve to reach the brain. However, this does not necessarily mean any electrical impulse becomes consciously registered as sound. Sensory receptors constantly receive input from the sense organs, and the information processing limits of the nervous system determine which sensations reach the conscious mind. Stimulus intensity must be high enough so that one becomes aware of a sensation. Even when maintaining a steady stimulus, though, inhibitory modulation can cause a threshold to shift in relation to the stimulus, dampening the signal and causing decreased perception (Eimer & Shlaghecken 2002). These thresholds of the nervous system are thus more variable than the ear's mechanical thresholds, as they are constantly subject to biochemical processes.

Perceptual Thresholds

Because the processes of material thresholds happen before a listener can perceive a sound, they are by definition subconscious. The perceptual thresholds that a signal crosses from electrical activity to conscious experience, however, are what give rise to conscious experience. Perceptual thresholds are more fluid than material ones, as they are not defined by physical properties but by the current 'state of mind' of the perceiver, how concentrated or distracted they are at a particular point in time. The act of listening happens at various levels – a superficial awareness of sound in background listening can be developed into a deep listening practice, by paying attention to details in sound, their development over time, and the effect they have on the listener and their body. Actively engaging in sensory awareness is a way of shifting the perceptual thresholds, to consciously explore the body's role in pre-rational perception (Hurlburt et al 2009).

Sensory Experience in 'Words'

While analytical descriptions may provide clarification in placing perception within the physical realm, we cannot assume to adequately express the sensory experience in purely rational terms. As Merleau-Ponty notes; "seen from the inside, perception owes nothing to what we know in other ways about the world, about stimuli as physics describes them and about the sense organs as described by biology" (Merleau-Ponty 1945, 240). Becoming aware of one's body and the way it responds to and shapes sensory input is not meant to separate the body from the perceiver, but to enhance the relation of inner experience to the outside world. It shows that perception is not merely a passive absorption of stimuli, but an active embodied response that continuously guides lived experience. Sense does not have to reduced to its abstracted meaning in reflective thought, but can be appreciated for its working as "meaning so directly embodied in experience as to be its own illuminated meaning" (Dewey 1934, 22). What this means for music is that any experience of sound, affected by bodily processes, is like an analogy for the material event from which it originates. What we hear is not just a distant event, but also the involvement of our body in the culmination of processes leading to the experience of that event.

Touch(ing sound)

Active Perception

Besides listening, sound can be made accessible through touching, too. Where hearing and seeing are teleosenses – giving access to objects or events recognized as existing at a distance (Fulkerson 2012) – touch is usually identified as located within the sensory organ. The tactile experience connects one physically to the object of perception, as the location of the perception on the skin corresponds to its perceived location in space. By actively involving the body in perception, as touching necessarily does, the world becomes part of the body, and the body part of the world. This entanglement dissolves the common distinction of action and perception: the world enters the body through touch on a physical level so that the subject is simultaneously acting upon and experiencing the world. In discussing haptic exploration, the active tactile perception of object properties, Lederman and Klatzky conclude that "the hand (more accurately, the hand and brain) is an intelligent device, in that it uses motor capabilities to greatly extend its sensory functions" (Lederman & Klatzky 1987, 367). This is especially relevant to instrumentalists, who use their hands in both acting upon their instruments and perceiving the response to their action. A player can embody their instrument by total integration of action and perception, when the player understands the workings and response of their instrument like it understands their own body.

Audio-Tactility

As one becomes aware of their sensory experience, it becomes apparent the senses are not as discrete as they are usually assumed to be. The body at the center of experience does not prioritize or order signals in the same way the conscious mind may do – when a situation is experienced in its raw form, senses blend or become one. In conscious, detached experience, the senses are usually separated so that one can describe them in isolation. This is a reduction of the multidimensional process that takes place in the continuous merging and separation of sense, and the chaotic stimuli crossing thresholds to facilitate consciousness. For example, what one hears is influenced by what they see and feel at the same time (Raij & Yousmaki 2004). The vocabulary used for describing sound reflects the continuity of sense – roughness, hardness, warmth, or clarity are concepts lifted from the tactile and visual domains applied to timbre. Hand-eye coordination is the most common example of how the senses are intertwined, connecting tactility and vision through the kinesthetic sense. Hand-eye coordination cannot be developed by 'learning about', but by experiencing. Extending this to listening, hand-ear coordination can be defined as the matching of tactile and audible sensations and the embodied motor response to sound through touch.

Touching Sound

Tactual projection (Fulkerson 2012) describes how someone may feel a surface by touching it 'through' an object – an instrumentalist may touch a resonating membrane or string through their mallet or bow, allowing them to touch further than the limits of their skin. This concept can be extended theoretically to an experience of touching sound. If a hand can touch a string through a bow and feel the tactile vibration that produces sound, that hand can be said to feel the sound, too. Tactual projection can then mean that an instrumentalist *feels* the sound of their instrument when they are playing it. Disregarding the idea of an instrument altogether, one can be said to touch sound when handling any material that has sound-producing properties. The potential sounds that can be made by interacting with an object are its acoustic affordances. These affordances arise from the interaction between a body and its environment, as Gibson says: "They are not just abstract physical properties. They have unity relative to the posture and behavior of the animal being considered. So an affordance cannot be measured as we measure in physics" (Gibson 1977, 120). Tactility, in allowing for acoustic events to take place, always leaves its mark on the sound produced. When a performer touches a sound, the sound is touched by them, and will carry an imprint of their interaction.

The Body in Resonance

The aim of above reflections is to bring to the attention the layers of subjectivity that the body brings to action and perception. Experience of sound is never static; it develops continuously as the body allows one to physically empathize through sound. The bodily imprint in a sound contains the entire experience of bodily understanding, sensory awareness, embodiment, and audio-tactility. A listener can hear the gestural movement of a performer in the produced sound; a performer can hear their body in the sound of their instrument.

This approach allows me to imagine a signal flowing from a performer's personal musical impulse, expressed through their body. This signal becomes vibration through the meeting of body and instrument, and is carried by air to become sound when heard. So the signal returns to the performer, whose musical impulse is affected upon hearing it. A feedback loop is created, in which the performer's body is fundamental in translating between experience and matter (Paine 2002). The body acts as a transducer, converting the signal from 'event' to 'phenomenon', in various ways. The signal continuously undergoes a sequence of transductions, each leaving a unique trace through their conversion. Through my ears I hear one version of the signal, through my fingers I feel another. Playing an instrument provokes this feedback loop, allowing me to hear my actions, and act on my sound.

The body is brought to resonance when it successfully acts as transducer within this feedback loop, meaning it transmits a signal analogous to what it receives. A performer thus 'tunes in' to this process, immersing themselves in the sensory experience of the instrument and trusting their instrument to react adequately to their body. An instrument that brings the body in resonance may, at its best, allow a listener to hear the reciprocity between phenomenal experience and material world.

3. Digital Oppression

Interfacing the Body

Having examined the concept of the bodily imprint, its origin, transmission, and consequence, the following chapters will consider how a practice may be formed around it. Continuing the idea of a signal flowing through the musician, their body, and their instrument, I made various instruments[2] that encourage the performer to make the body audible, as if to hear tactility and feel sound, aiming to somehow *amplify* the bodily imprint. The instruments are electroacoustic in the sense that they use electronic means to produce or augment sound. My reason for using electronics is to accommodate for the corporeal expression by enhancing the audio-tactile experience. In doing so, a performer gains access to sound at a strongly embodied level, in order to bring the body in resonance.

The difficulty that arises in using electronics for this particular purpose is in their objective foundation. As defined in chapter 1, the bodily imprint is 'an imposed projection of bodily understanding through the creative act of listening'. To recognize a performer's body in the sound they produce, one must know what it means to have a body that can dynamically engage with its environment. This is a purely subjective listening mode, rooted in personal experience. Amplifying the bodily imprint electronically is thus not simply an extraction and amplification of an objective acoustic feature – it inspires a reconsideration of digital mediation (current chapter) and transduction techniques (next chapter).

The Digital Disregard of Embodied Navigation

Instrumental Immediacy

Let us start by looking at the experiential difference between navigating instrumental and digital structures. An instrumentalist typically relies on their bodily knowledge to play their instrument. After practicing physical movements and intonations, they can act through their body without having to consciously decide on each step of each action. In this embodied state there is an immediacy to the navigation of the material. The performer may consciously reflect on what they are doing, while they are doing it, but this reflection is an abstracted representation

[2] (While not all were used in staged performance, the word 'instrument' is used here to denote a tool that incorporates both physical and digital structures.

already past. Their actions happen in the moment. As a performer's movements guide the material events, the sound is a reflection of this moment, inseparable from the action that produces it. The sound is not a final conclusion of some planned movement, but a moving part of the action itself.

For the acoustic musician, the physical interaction is essential to the production of sound. Their body, as it is matter, acts within the same material realm as their instrument and the sound it produces. They materialize the musical impulse through their body, in order to make it audible through their instrument. In moving their body in accordance with the instrument's potential for sound, a performer's movement is simultaneously perceivable in various degrees as sonic, tactile, and visual. The embodied state of playing allows a listener to physically identify with the performer's actions through their own body, and in doing so they may *understand* the physical movements that produce the sonic movements.

Navigating the Digital

About this understanding by identification, Alva Noë writes: "to be a perceiver is to understand, implicitly, the effects of movement on sensory stimulation" (Noë 2004, 1). Of course, it is essential that the listener is a *human* perceiver; this understanding of sound, a thought without words, is a result of pre-linguistic bodily knowledge. Any words used to describe it reflectively will, at most, be an approximation: language disregards the body's subjective experience in favor of a shared description of sound (Massumi & Manning 2014).

This poses a problem for the musician looking to incorporate digital technology in their work: the digital world, constructed of quantitative difference and mediated by language (Galloway 2019), has no human body to acknowledge the bodily imprint with. Software creates a finite space, bound by pre-defined ranges and processing power. To navigate through this space, intended operations must be described within the known model. Musical experience, however, does not originate in models or symbolization. If the musical impulse must be expressed through language, the body is left behind.

Quantifying Expression

Communicating with a computer means expressing oneself in a modality that the computer 'understands'. In order for a system based on language to do computation, multidimensional action must somehow be made one-dimensional data. The quality of communication is based on the scope and clarity of the language used, often leading a performer to base their actions on the system's perception of control data. In this act of approximation the performer's intricate understanding of their body is disregarded in favor of precision and repetition (Ryan 2006).

The issue here is that any mode of inputting data to the computer then assumes a submission to the digital system. Digital control forces one to describe sounds in isolated parameters, detached from their source. A well-known example of this generalization is the MIDI protocol. In order to connect as many different instruments as possible, this general standard is meant to represent any kind of control as an 8-bit number range. Expression has to be quantified in order to act on a realm of numerical representation. With this, the physical mode of operation is made arbitrary – any movement is condensed into a set of numbers for the computer to interpret, leading the performer's intention to be abstracted as it becomes a specific collection of data. This type of control, which assumes musical parameters can be absolutely measured and discretized, creates instruments that only accept submissive modes of behavior.

4. Transduction

Transducers

The word 'transducer' in electronic music technology typically refers to a specific electromechanic surface transducer that converts an electric signal, usually audio, to vibration. I use it in a much broader sense: as the location at which a signal is converted between media. An object that acts a transducer carries a signal between channels. In my description of the body as transducer, which translates between matter and experience, we have seen that this concept in fact may host many different acts of transduction: a signal is converted from sensory stimulus, through mechanical, chemical, or electrical channels, to give rise to consciousness. Similarly, the electromechanic surface transducer, in converting current to air pressure, contains sub-transductions through electromagnetic and material (acoustic) channels. The concept of the transducer can thus work as a black box to compare a system to its environment, in which I am more interested in its in- and outputs than the specifics of its operation. This chapter will focus on the transducer as a tool for converting between the digital and the mechanical, and its effect on the processes of control and excitation.

Transparency

Each medium leaves a trace of its qualities on the signal that passes through its transducers. The bodily imprint has been described as the trace left by the body, and the digital affects a signal by manner of abstraction and quantification. As explained in the previous chapter, movement through the instrumental structure is limited only by the physical world (that the body naturally inhabits), but movement through the digital structure is restricted by finite representation. This means the digital can only be navigated in so far as there is physical access to it, in the form of control input and generated output. A digital musical instrument requires hardware that yields access to the software, by using transducers to materialize the digital system's in- and output structure.

A *transparent* transducer is one that minimally affects the signal. Transparent transducers are typically used for communicating with the digital, as they don't interfere with the signal they carry. When tangible in- and outputs on an interface refer directly to a digital representation, transparent transduction allows a user to physically navigate the digital system. However, this transparency is a result of favoring the digital signal over the material one – by assuming the representation as 'truth', the role of the transducer is to obediently depict the digital signal.

Meaningful Action

For the bodily imprint to be audible, a sound must carry enough bodily traces for a listener to identify with it through their own body. The manner of recording these traces is not done by objectively analyzing an acoustic signal and defining its properties like an information retrieval system might do, but by composing interactions that deepen the involvement of the body. Capturing the physical in the digital does not always go by way of most efficient conversion. Physical interactions thus do not have to merely accommodate a digital state, like transparent transducers do – they can be an essential part of the performer's expression. What is desirable in searching for interactions that can carry a performer's subjectivity is to maintain meaning ("so directly embodied in experience as to be its own illuminated meaning" (Dewey 1934, 22)) within the actions themselves.

According to Trevor Wishart, "the translation of performance-gesture into the gestural-structure of the sound-object is most complete and convincing where the technology of instrument construction does not present a barrier." (Wishart 1985, 17). The transparent transducer may easily introduce a barrier for the bodily imprint, as its obedience to the digital system shifts affordances out of the physical and into the virtual. This brings two issues, which I identify as problems of *control*, or the input to the system, and *excitation*, its output.

Control: Physical Access

Transparent Mapping

Access to the digital is composed by defining relations between physical actions and the virtual system. In the most common physical interfaces for digital control, the performer relates to software through rigid electromechanical transducers, such as buttons, switches, sliders, potentiometers, or joysticks. These transducers provide access to the digital structure based on relating a physical position to a digital range. This absolute relation of the physical to the numerical is useful for its predictability, but in effect only approximates the intricacies of the performer's physical actions. Seeing as these interactions are inherited from traditions of military and scientific technology (Holmes 2012), they are more concerned with precision than expression. These transducers can thus be called ‘transparent’ transducers: their purpose is to mimic the digital structure as efficiently as possible, thus hiding themselves.

The word ‘mapping’ – making connections between physical and digital structures – already indicates a loss of dimensionality. It implies a reduction of potential by the processes of separation and quantization inherent to the digital representation. Mapping the digital to the material allows the performer to navigate a structure that *represents* sound. A musician can then physically interact with the digital structure, but only in so far as this structure is programmed to be open to interaction. When using these transparent transducers, physical affordances are constrained by the digital.

Control Alternatives: Fabric Sensor & Contact Microphone

In my personal practice I have used two kinds of input transducers: fabric sensors and contact microphones. These offer a way of generating or affecting an electrical signal based on material properties. Fabric pressure sensors measure applied force through piezoresistance; contact microphones pick up structural vibration through piezoelectricity. In both, an ADC (in a microcontroller or audio interface) then converts the electrical signal to digital data. Using these transducers, material events (pressure and vibration) become the foundation of digital control, presenting a comfortable medium for tactility and vibration especially appropriate for musical instruments.

The fabric pressure sensor, described more in-depth in chapter 5, consists at its core of two conductive materials separated by a piezoresive material. It works as a variable resistor, in which an increase in pressure leads to an increase in current passing through. An ADC digitizes this signal, and so the combination of the pressure sensor and a microcontroller can be seen as a transducer that converts force to data.

Especially in homemade sensors like mine, this conversion is non-linear – the sensors can be very sensitive to light touch, but then need increasingly more force to reach minimum resistance (Perner-Wilson (1) n.d.). Additionally, a user can *feel* how much pressure they are applying. This tactile feedback means a user uses bodily understanding to get a sense of control. The non-linearity and physical contact demand a tactile awareness from the user, linking action and perception to maintain the desired state. This allows the fabric pressure sensor to retain its materiality, separate from the digital structure it is connected to.

The contact microphone picks up an object's acoustic vibrations. The combination of object, microphone, and ADC makes a transducer that converts sound to digital data. This transduction is non-transparent in the sense that any interaction with the object is shaped by its acoustic qualities before being digitized. This means physical affordances, and all their complexity and degrees of freedom, can become data. If the output of the system then converts this data back to sound, the object preserves its acoustic affordances in the output signal. This is, of course, highly useful for the bodily imprint: physical interaction remains fully embodied, while simultaneously presenting a digital system with data.

Excitation: Past the Loudspeaker

The Transparent Loudspeaker

The digital musician uses their body to navigate a control structure that only represents a deeper, digital structure, which in turn produces a signal that becomes sound. If the output of the digital system is considered the 'sound' of the instrument, the loudspeaker used to materialize it is assumed to accurately represent this signal. The loudspeaker receives an analog audio signal from a DAC and converts it to physical vibration through electromagnetic transduction. Just like in its input structure, the digital dictates output transduction to be transparent, too. The listener is expected to listen *past* the loudspeaker, to hear the sound it is programmed to produce. When one listens for the performer's body in a sound, the potential for bodily imprints to be carried through a detached loudspeaker is further reduced.

An additional effect of the loudspeaker is that sound production and control are separated. The physical detachment of an instrument's sound from its control interrupts the body's natural capacity to experience and respond to sound as an audio-tactile event. The most straightforward approach to audio-tactility for the digital musician would be to simply touch their loudspeaker. Unfortunately, the design choices that make a speaker transparent also make it bulky and fragile.

Excitation Alternatives: Surface Transducers

A more approachable way of inviting tactility is by activating materials using electromechanical surface transducers. Like the contact microphone, the surface transducer connects digital data to material vibration in such a way that the body can interact with the digital without having to act digitally. The usual surface transducer is meant for rigid materials like wood, plastic, or metal. In my practice I have found that by using embroidered electromagnetic coils and magnets, fabric materials can be activated and brought to vibration, too, described further in chapter 8.

Activating an object like this makes sound both audible and tactile, so that a strong sense of ‘touching sound’ is encouraged. When a person touches an activated object, they affect its vibration by dampening or exciting a certain part. This form of audio-tactility effectively makes the body a part of the transduction of data to sound, which then carries an imprint that is a combination of the object’s resonant properties and the body’s particular way of dampening or exciting these properties. While the tactile experience of this transduction is highly private, the sonic experience lets a listener hear the entanglement of body, instrument, and sound.

Giving the Digital a Body

Permitting the bodily imprint in sound means being sensitive to the nuances of bodily understanding, and the complex way the body experiences matter. Digital instruments aiming to convey the body need transducers that effectively pick up these nuances and complexities. The aim of the transducer in this situation is thus not to make itself transparent in submission to the digital, but to vividly emit materiality so as to invite embodied action. In other words, to give the digital a body so that we can communicate with it.

This view on the digital instrument draws on the relationship between the human body and the consciousness it mediates. As the body makes sense of the world, it embeds this perception with subjectivity. Similarly, the physical body of the digital instrument shapes the data the software receives. My approach to designing the interfaces in the following chapters is thus concerned with the transductions that happen between these bodies.

5. Performing Bodily Understanding: *Stability* (2019)

Tactility & Electronic Textiles

My approach to converting matter to data started with a reconsideration of the usual digital music interfaces. Considering the rigidity of traditional sensor hardware, I decided to find alternatives in electronic textiles. By replacing plastics and metals with fabrics and thread, constructing sensors is a way of approaching the digital from a tactile perspective. These ‘soft sensors’ invite tactility because textiles have historically and culturally always been close to the body, in clothes, blankets, or furniture. Their materiality is so familiar that we barely notice their presence, and surround ourselves with woven, knitted, and sewn fabrics (Gallace & Spence 2011). The structure of fabric and that of the digital are not completely unrelated – the punched card mechanisms of the Jacquard weaving loom was the precursor to early mechanical computer mechanisms, and some claim weaving to be the first binary art form (Harlizius-Klück 2017; Stewart 2016).

> “As we find ourselves living in an increasingly virtual world, there is a growing need to engage with the **real**, with haptic and tactile qualities inherent in physical things. The greater the interaction with electronics, the greater the need seems to be to ‘touch base’, to get back in touch with the rhythms of nature, with haptic objects. Craft has a valuable role here – not to hark back to the old days, but to embrace new technological developments in materials and processes, and to mix them with tried and tested methods that have served humans well in the past.” (Harvey-Brown 2012)

Using textile as the starting point for digital communication adopts a tactile experience that is easily incorporated into the body. It is a way of bringing interaction close to the skin, in a medium the body is naturally comfortable with.

Balancing & The Pressure Sensor

Specifically, the fabric pressure sensor (which can, due to its elasticity, also function as a bend or stretch sensor (Perner-Wilson (2) n.d.; Harris, 2014) is a way of measuring effort that has to be continuously exerted in order to maintain its value. Pressing on the fabric to reach certain states incorporates the tactile coupling of action and perception, as the user has to constantly balance applied force and perceived resistance. This idea of the balancing involved in a pressure sensor was dramatized in *Stability*, performed at STEIM in June of 2019.

***Stability* (2019)**

In *Stability*, the performer wears a sock with four textile pressure sensors under the heel, forefoot, and toes. The sensors are part of the sole of the sock, by sewing four areas of conductive thread in a layer of fabric on each side of a piece of piezoresistive foam (described further in appendix B). These sensors are wired to a Teensy microcontroller, which sends serial data to eight synthesized signals in the SuperCollider programming environment. The four sensors control the amplitude and frequency of four sine waves, and simultaneously the tension and rhythmic speed of four percussive physically modeled membranes. Through distributing their weight over the sensors, shifting their balance both purposefully and reflexively, the performer sonifies their struggle and cooperation with their surroundings.

Stability, at Rear Ear #3 (STEIM, June 19, 2019)

The four parallel sensors create a fairly simple four-channel structure, each sensor controlling a similar digital range. However, the four ranges have certain fixed relations to each other by design of the foot. Since each location has a fixed location on the sole, they can hardly be navigated completely independently. As the applied pressure is a result of gravity, the total pressure should be relatively stable. This means that when the performer lifts their heels, more weight is shifted onto the toes, and the pressure sensors reflect this in their signals. This inherent physical relation of the sensors to each other means the signals reaching the digital do not require intricate mappings in order to reach sonic complexity.

Sound

The sensor controlling the fundamental frequency of the four sine waves, that is the root for the three harmonics, is located under the heel. This area of the sole usually endures the greatest amount of pressure when standing, so that the body remains stable and needs minimal help from the forefoot in balancing. When the heel is raised and the body balances on the forefoot and toes, the weight distribution is insecure, chaotic, the entire leg is tense, suspending the eventual resolution of landing on the entire foot. In the same way, removing the fundamental frequency of the four tones causes a tension in the harmonic structure of the sine waves. Although the sound in this performance came from the P.A., low frequencies tuned to the room were used to bring about an experience of tactility. This way, the audience comes in touch with the sound through the rumbling of the space.

As it becomes clear the presence of tones and rhythms relate to the points of contact between foot and floor, one can listen to the body: uneven weight distribution is communicated through phasing rhythms and beating frequencies, the body's instability appears through movement of these rhythms and frequencies.

Performance

In this piece, the performer explores the (in)stability of their body when confronted with gravity and imprecise muscle response. This piece aims to bring bodily understanding to the foreground by amplifying the processes of balance stabilization in a sonic performance. The performer is in dialogue with their environment, controlling sound and structure through their foot. The sound is a result of the body as transducer, performing the 'noise' inherent in their system of control. By leaning on one foot, the performer tires out their leg muscles, requiring ceaseless readjustment to maintain a steady stance. This readjustment is never a precise movement, but an estimation that over- or undershoots its target, leading to reflexive movements and an inability to lock on a central point of balance. While the performer's focus is on the sounding output of the system, they are present as both a performer and an observer, switching between purposeful and reflexive movement.

Tactility and kinaesthesia are merged with hearing by programming a direct relationship between the pressure sensors' input and the sonic output: the higher the pressure on the sensor areas, the higher the frequencies and amplitudes of the eight signals. The performer is at once concentrating on how the floor and the sensors feel under their foot, how their body's swaying is caught by the different areas of their sole, and how these sensations are present in the resulting sound. The simultaneity of the material and sonic experiences causes the sound to be located in the foot, the leg, the body, the performer – not in the computer on the floor to the side of the stage.

The performance in June 2019 personally felt very dramatic. The setting sun and the warm spotlights already made me aware of my body, and throughout the 10 minutes of balancing I pushed myself to the edge of exhaustion, sweat dripping down my face. The act ended with a dramatic fall off the podium, proving the inability to maintain a steady signal through the body.

6. Audio-Tactility: *Touching/Feeling* (2019)

In this audio-tactile installation a wooden board lays on cushiony foam, with four pressure sensors underneath. These cause a transducer attached on the underside of the board to vibrate when touched by a participant. The four sensors under the corners of the board control the amplitudes of four sine waves, which are synthesized using a Teensy microcontroller with a Teensy audio board that sends the signal through an amplifier to the transducer. Pressing the wood through the foam accesses the sensors, and thus the wood becomes a transducer of action to data, shaped by material qualities of the wood and the foam.

Touching/Feeling, at CASS *Multimedia Festival (KABK, May 20, 2019)*

The physical boundary between participant and object – human skin and wooden surface – is emphasized in this work, by activating the object in such a way that it responds to human touch. Like the participant, the board works as both a sensor and an actuator, and the physical location of the tactile interaction is emphasized in this mirroring. The participant and the board cannot *touch* the other without also *being touched by* the other. A fusion emerges in their relation, where the vibration brings about an audio-tactile awareness of sound within the participant. The processes of transduction in their sense experience allows a certain sense of touching sound, especially because the vibration only starts once the participant initiates contact.

While I think this installation has a certain strength in its simplicity, it lacks a depth in terms of affordances. The experience that is evoked seems to me more a statement of a phenomenon than that it invites interaction. Although its activation is dependent on human intervention, there are relatively few degrees of freedom in the interaction. This inspired me to involve the body more deeply in the physical production of sound, by combining the feedback network of perception with acoustic feedback, described in the next chapter.

7. Navigating Resonance through Feedback: *Wood* (2019)

Resonance

The previous chapters have described how material vibration gives rise to different abstractions in sensory experience and digital representation. The body is fluid, fleshy, imprecise, and continuously adjusting, while the digital is solid, precise, and discrete. In amplifying the bodily imprint, the goal is to create a physical situation that magnifies the trace of the body on a signal. Combining material transducers (such as the human and instrument body) with the transparency of the digital, a signal traveling through this network can be amplified electronically, while being expressed materially. This brings the imprints, the specific characteristics of the transducers, to the foreground.

Resonance, "the intersection of a system, regardless of its size and complexity, with its self and its 'not-self'" (Gershon 2013, 2), emerges when a transducer is somehow sympathetic to the signal traveling through it. If the transducer's imprint is similar to the signal itself, mutual qualities are amplified. This is why a room's impulse response is captured with a sine sweep: the acoustic imprint is tested against each frequency to find all possible resonances. A person can be said to resonate with their environment, when they have an awareness of being in relation to the world (Gershon 2014) – as if their experience, body, and environment are strongly connected. The body in resonance as described at the end of chapter 2 is imagined as a corporeal transducer actively guiding the bodily imprint.

Feedback

To truly bring out the resonance of a system it can be set into feedback, by connecting its outputs to its inputs. Feedback creates a circular chain of transduction, and, when this chain involves sound, is a way of activating a space or a material to bring out its sonic possibilities. A signal passes through this chain and is imprinted by transducers in every passing. In a positive feedback configuration, "a deviation of the system in a certain direction will produce a further shifting in the same direction, and the behavior will be that of magnifying the effects caused by the stimuli" (Sanfillipo & Valle 2013, 14). Anything inside the feedback network thus becomes part of the signal, allowing each transducer in the circular chain to affect the sound. Effects of the various transducers accumulate, amplifying unstable qualities happening within.

By making the body the most unstable part of the network, the sound takes on some characteristic of the bodily imprint, and becomes a reflection of the performer's interaction.

The circular feedback network is a non-hierarchical structure: the signal flowing through it has no single origin, and is presented differently at various points in the network. The sound of the network depends on where we listen in on it, as the audibility of certain transducers varies between points. This is important to consider when trying to express the bodily imprint in sound – I want to listen to the network at a point where the body is most pronounced.

Resonance & Stability – *Wood* (2019)

The feedback network is attractive to me as it creates a continuous sonic event that amplifies instability. Since the most non-transparent transducer will get amplified the most, it provides the possibility for bodily imprints to materialize. In *Wood*, I created a semi-open feedback network by setting up a surface transducer and a contact microphone in feedback through a wooden board. When this system is set into feedback, the inherent noise of the system is amplified and the wood starts vibrating. As it hangs from two thin wires, it is physically decoupled from other objects, meaning the signal passing through the system is affected most by the material properties of the wood. The increasing noise excites the particular resonances of the object, which are then picked up by the contact microphone. When a feedback network's properties remain unchanged, it stabilizes in such a way to produce a specific sound that reflects the current state of the network. 'Stability', here, produces resonance: if the signal passing through the chain remains relatively unchanged, the sound settles in periodicity. In the case of the wooden board, the system stabilizes on its dominant resonant mode.

The resulting sound is a product of physical, electrical (signal processing quality of the hardware), and possibly digital (signal processing quality of the software) properties of this feedback network**.** In *Wood*, the electrical and digital properties were fixed and transparent, so that the physical properties most affected the feedback network. The sound is thus an amplification of the board's resonant modes, which can be navigated by the performer's hands.

Playing *Wood* by dampening the material.

Balance

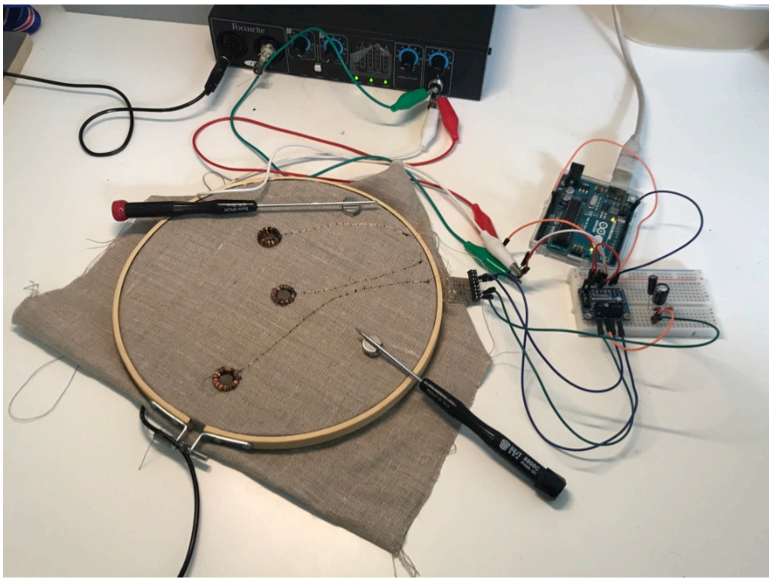
In *Wood*, the performer interacts with sound at its material level. Holding and dampening the vibrating board with their fingers allows them to 'play' the feedback chain, as they can feel the sound traveling through their arms. The body acts as a transducer in a very physical way, affecting sound waves directly. This means the performer does not have to think in descriptive terms such as pitch, loudness, or timbre. Instead, as "a modification of one sonic feature can potentially lead to modifications in all the others" (Sanfillipo & Valle 2013, 15), they can experience sound as a material event, a reflection of a situation happening in 'the now'. Interacting with the network happens through the fingers, where the body's precise control of *balance* allows the performer to find points of interest: one can navigate a feedback network by balancing on certain resonant modes. 'Balancing' then means producing a stable output under changing conditions – exploring the edges of resonance without falling off. Additionally, the wood is flexible enough that it can be bent slightly, shifting the natural resonant modes. Balancing, dampening and bending leads to an improvisatory mode of interaction, often the case in feedback networks:

> “Because he or she is forced to dynamically interact with the dynamic system in the design of the performance, an improvisational mood is often preferred to a fixed set of instructions. Also, as improvisation is a process where actions are causally related to listening, an aural feedback loop is established between the machine and the performer, the latter becoming an integral part of the overall system.” (Sanfillipo & Valle 2013, 23)

Although the instrument creates a strong sense of audio-tactility, the fact that the signal is continuously traveling through the network means the instrument is constantly activated. The instrument is thus independent of the performer – it does not necessarily rely on a human body to be activated. Because of this, the interaction, to me, feels more like ‘affecting’ than playing. The bodily imprint was a side-effect, rather than a foundational aspect.

8. Body in Resonance: *Hoops* (2020)

The desire to make a feedback instrument in which the performer was an essential part of the chain led to an instrument design I call the Hoop. A few versions were made, all consisting of an embroidery hoop with a piece of fabric stretched in it, to create a kind of membrane. Similar to *Wood*, the Hoop is a physical instrument that produces acoustic feedback with a contact microphone. The microphone is glued to the bottom of the stretched fabric, amplifying all contact sounds. The signal is processed digitally, and sent back to the hoop through an embroidered



The first hoop, showing embroidered coils attached to an audio amplifier. Magnets are stuck to ends of screwdrivers for performance. Black cable near the bottom comes from contact microphone attached to the bottom.

electromagnetic coil. By holding a magnet near the coil, the audio signal becomes movement, causing both the entire fabric surface and the magnet to vibrate. In this instrument, the magnet is attached to the end of any metal rod (screwdriver, fork), so that the performer feels the vibration of the magnet through their hands.

Electromagnetic Transduction

The coil-magnet combination works as a deconstructed surface transducer (as described in chapter 4). I started working with coils as an experiment in converting digital data to physical events. The first coils I made, I embroidered onto a light fabric that I hung parallel to a magnet. By sending it a basic binary high/low signal, the fabric started attracting and repelling the magnet. This caused the fabric to subtly move and ripple while being pulled down by gravity, almost as if it were dancing. The beauty in the movement was a result of the way the coil and the fabric converted a plain, digital signal to a deeply affective experience of material. By sending an audio signal to the coil, the fabric becomes like a loudspeaker, albeit not 'transparent' one – textile is not a particularly resonant material, as the soft threads easily dampen traveling sound waves. However, the vibration was powerful enough to move the fabric when stretched, and for a contact microphone to pick up the signal.

The physical separation of the usual parts of a electromechanic transducer – the coil and the magnet – requires a performer to enter the network. Holding a magnet near the coil allows a signal to flow, converting electric current to vibration by the electromagnetic force that arises from the coil. The stretched fabric vibrates from the sound of the signal, and the contact microphone then picks up this vibration. This creates a feedback network that is dependent on the performer's control of the magnet, and the sound is strongly determined by the distance between the coil and the magnet. This has to do with the relation between electromagnetic signal strength to space needed for physical vibration.

Holding the magnet at a distance generates a weak signal, but allows the surface more room for movement without touching the magnet, causing low frequency vibrations. The closer the magnet comes to the coil, the stronger the signal will be, and thus the stronger the amplification by the feedback network. However, when the magnet is close to the coil, there is less space the physical vibration can take up,

Left: activating vibration by holding magnet near coil. Right: bottom of a hoop, showing contact microphone and embroidery thread trace.

leading to higher frequencies. The more the magnet is pressed into the fabric, the more the feedback structure carries only high frequencies. However, these relations of location to frequency are not definite rules of the instrument's behavior.

The location of the coil in the circular surface also determines the exact resonances it picks up. Multiple coils thus allow for a variation of tones to be played simultaneously, by using two separate magnet-rods. The performer can, when very careful, harmonize two coils in feedback, even though the single contact microphone only picks up the combined signal.

The non-linearity involved in the acoustics and in the feedback network make it an instrument that requires constant engagement to feel where the sound is going. The performer must stay aware of what the instrument sounds like, but also what is feels like.

Affordances of Fabric Feedback

Additionally, the sound in the feedback loop can be acted on by deforming the fabric surface. Like *Wood*, the flexibility of the material allows for shifting of the resonant modes. The woven material is slightly elastic, so that a performer can push their fingers or hands into it, directly acting upon its resonant structure. This deepens the idea of 'balance' in the feedback network, introduced in chapter 7.

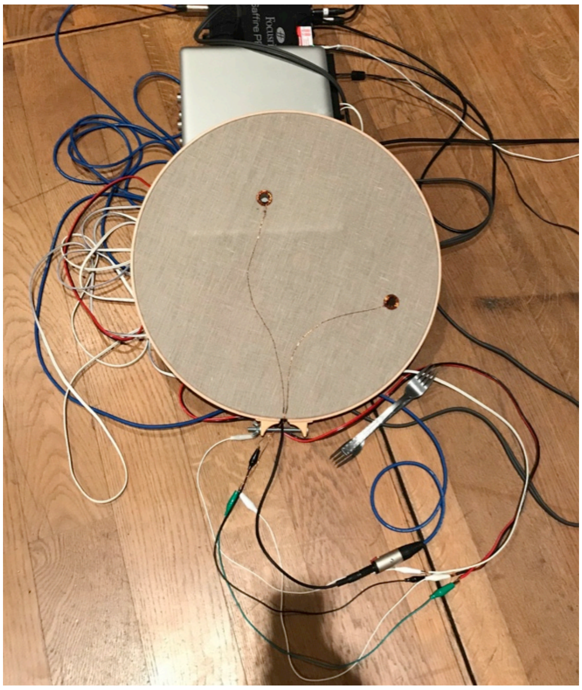
The performer thus has access to the sound signal through the magnets they're holding, and through touching the surface directly. The transductions involved are acoustic (resonant modes of the stretched fabric), electrical/digital (compression and amplification of the audio signal), and most importantly, bodily. The performer's body is subject to imprecisions through trembling, gravity, and magnetic force. The fact that the magnet is attached to a metal rod amplifies this added noise: the length of the rod exaggerates small movements. This causes the performer to accurately feel the vibration and the magnet to move even with involuntary tremors, especially when the hands start getting tired.

Because the contact microphone picks up any interaction with the instrument, it makes the surface into a kind of frame to which objects can be added. Sonic affordances can thus be extended materially, for example by pinning needles into the fabric.

Wichelroede **(2020)**

"*Divining Rod*: A rod made with certain superstitions ceremonies, either single and curved, or with two branches like a fork, of wood, brass or other metal. The rod is held in a particular way, and if it bends towards one side, those who use the rod believe it to be an indication that there is treasure under the spot."

(Encyclopædia Americana 1845, p.258. Presented as program notes for this performance.)



Left: the large hoop as performed in *Wichelroede*, at CASS #2 (KABK, February 18, 2020).
Right: photo from performance, showing instrument on lap.

In this performance I played a large embroidery hoop (⌀50cm), pictured above. The title refers to divining rods – wooden or metal rods used for locating water or other treasures, possibly even magic. The tradition of the divining rod intrigued me, as it is based on the user assuming a divine force is leading their path, when in reality they might be following reflexive trembling of their fingers. In *Wichelroede*, my divining rods are two forks with magnets attached to the ends, and the magic I am looking for is resonance.

Sitting cross-legged in the dark space, I tried to introduce the mechanism to the audience while keeping some mystery. Starting with light scratching on the surface to show its manner of amplification, I slowly added in slight feedback chirps through the magnet, leading to increasingly long drones. As described above, by pressing down on the surface and stretching it, I could tune the acoustic resonances. I did this to tune the tones to the resonant modes of the concert hall, causing objects to shake with sympathetic vibration. Comments by the audience afterwards informed me that the chairs and bleachers were resonating, too. This is exactly what I had hoped for – bringing the audio-tactile experience to the listeners.

Embroidered Sensors

The latest version of the Hoop is in a way a culmination of the three projects described in previous chapters. It combines techniques and lessons learned from each, by embedding fabric sensors, contact microphone, and electromagnetic transducer into one instrument. This version, pictured below, is currently a work-in-progress extension of the large hoop used in *Wichelroede*. It features embroidered pressure sensors that are connected to the Teensy microcontroller, to send serial data to Supercollider. The software now involves effects such as delay and pitch shifting, which affect the signal in feedback. This means the digital side of the instrument adds affordances to the process, which can still be controlled from the surface of the fabric.

These embroidered sensors, like the sensors in the sock in *Stability*, all move together when interacted with. Since they are all part of the same stretched surface, every movement on this surface will affect all sensors. The deformations in the fabric are carried through the woven structure, so even movements that are not directly on the sensors will be picked up.

In this configuration, touching the surface is captured in two ways: the contact microphone picks up the acoustic signal, while the sensors generate a control signal. Additionally, the sensors even pick up movement when the hoop is brought to feedback with a magnet, even without touching the surface or the sensors.

The interaction and resulting sound is always shaped by and dependent on the performer, making it into a highly responsive instrument. By picking up nuances of the performer's hands, activating acoustic resonance from touchable material, and spreading the tactile experience through the performer's whole body, this instrument exemplifies the body in resonance.

The latest version of the large hoop (May 2020), showing two coils, on of which surrounded by two embroidered pressure sensors.Black cable from the bottom is attached to the contact microphone. Embroidery needles, used for additional sounds, seen in top right.

Conclusion

This thesis introduced the 'body in resonance': an experience of sound that unifies subjective experience and physical matter. My approach to resonance incorporates both its acoustic and its affective sense. In resonance, the body is sympathetic to its environment – a performer resonates with their instrument, a sound resonates with a listener. Bringing the body to resonance is a way of engaging in physicality while retaining subjectivity, using sound and the body to somehow consolidate experience and matter.

The body in resonance is based on the idea of perception as an active embodied response. The body stands between physical events and phenomenal experience, affecting both in translating between the two. The bodily imprint is a trace left by the body during this translation, relating experience to matter. This unique reflection of a performer's body in the sound they are producing connects concepts of bodily understanding, sensory awareness, embodiment, and audio-tactility. An instrumentalist's act of producing sound imprints that sound with their body, and a listener hears this imprint through bodily sympathy.

The practical aim of this research was to bring out this resonance, by creating instruments sensitive to bodily imprints. Since the bodily imprint has an inherently human, subjective foundation, concepts of digital mediation and transduction were evaluated and led to instruments designs that invite tactility. These instruments use electronic means to amplify the bodily imprint. By using techniques involving electronic textiles, feedback networks, and electroacoustic transducers, they provide access to the digital without quantifying expression.

This does not necessarily mean that the instruments and techniques described here contain the resonant experience – they only set up a situation that is sensitive to the body. It is up to the listener to be sensitive, too.

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Appendix A: Notable Materials Used in Fabric Sensors

Conductive thread is sewing thread that conducts electricity. The type used in the presented works is 2-ply stainless steel fiber with 16 ohms resistance per foot. This means it is strong and smooth, and will not oxidize over time (like silver thread does). It can be easily threaded through thru-holes to connect to circuit boards. It is difficult, but not impossible, to solder conductive thread circuitry. Hot glue is used to secure knots, keep ends from fraying, and isolate the thread from its surroundings.

Velostat is a carbon-impregnated polymer foil, used for antistatic packaging of sensitive electrical components. Its molecular structure allows it to conduct electricity with varying resistance depending on how much pressure is applied to it, making it piezoresistive. This means it can be used to create a variable resistor when placed between two conductive materials. A soft sensor created in this way is sensitive to pressure, which can be applied either by force or by bending or otherwise deforming the sensor.

Neoprene is a synthetic rubber with fabric fused to either side. Its flexibility and insulating qualities make it widely used in for example laptop cases, wetsuits, and Rhodes hammer tips. It is moderately stretchy, easy to sew with, and its layered structure allow for conductive thread to be easily insulated. Its 'squishiness', or material dispersion in response to deformation, smooths contact pressure. This means individual points of contact placed close together on one side will deform the fabric on the other side as a unified 'bump'.

Metal snaps are small discs that interlock for secure fastening. Usually used in clothing and bags for attaching fabrics or closing pockets, they are easy to sew with and attach to fabric. Metal snaps are conductive and solderable so they make a useful connection in detachable electronic textiles,

The *Teensy* USB Development board is a microcontroller that communicates through the Arduino programming language and can be used to read and write serial data from a computer over USB. With the Teensy audio shield it becomes easy to create basic audio processing and synthesis programs and upload them to the microcontroller, for use without a computer. In this case it works as a 16-bit, 44.1 kHz audio interface. In the presented works, the Teensy version 3.2 was used.

Appendix B: Technical Details of Presented Works

Stability

Presented at Rear Ear #3, STEIM, June 2019

In this performance, the performer wears a sock with four pressure sensors sewn into the sole, under the heel, forefoot, and toes. These sensors are wired to a Teensy microcontroller, which sends serial data to eight synthesized signals in SuperCollider. The four sensors control the amplitude and frequency of four sine waves, and simultaneously the tension and rhythm of four percussive physically modeled membranes.

The three layers of the pressure sensitive sole.
Left: neoprene layer, containing four traces of separate strands of conductive thread, that connect to the Teensy's analog input pins.
Middle: piezoresistive foam.
Right: neoprene layer, containing one long pice of conductive thread, connected to the Teensy's voltage output.
The exposed strands of conductive thread on either neoprene layer are matched in location, so that they would be touching if it weren't for the foam layer.

The sole consists of two layers of neoprene fabric with piezoresisitive foam in between. While wearing it, I marked four points on the sole where I put the most pressure when standing, and used exposed conductive thread to make 4 pressure sensors like in *Touching//Feeling*. Using foam instead of velostat for the resistive layer was done here because it allowed for more control of touching the floor through the foot. The extra padding made it easier to feel when the foot was close to the floor, and was sensitive enough to pick up small shifts in pressure.

Sewing the sole. The foam fits exactly in between the two layers of neoprene, and the entire sole is then sewn on to the sock (sole made specifically to match this sock).

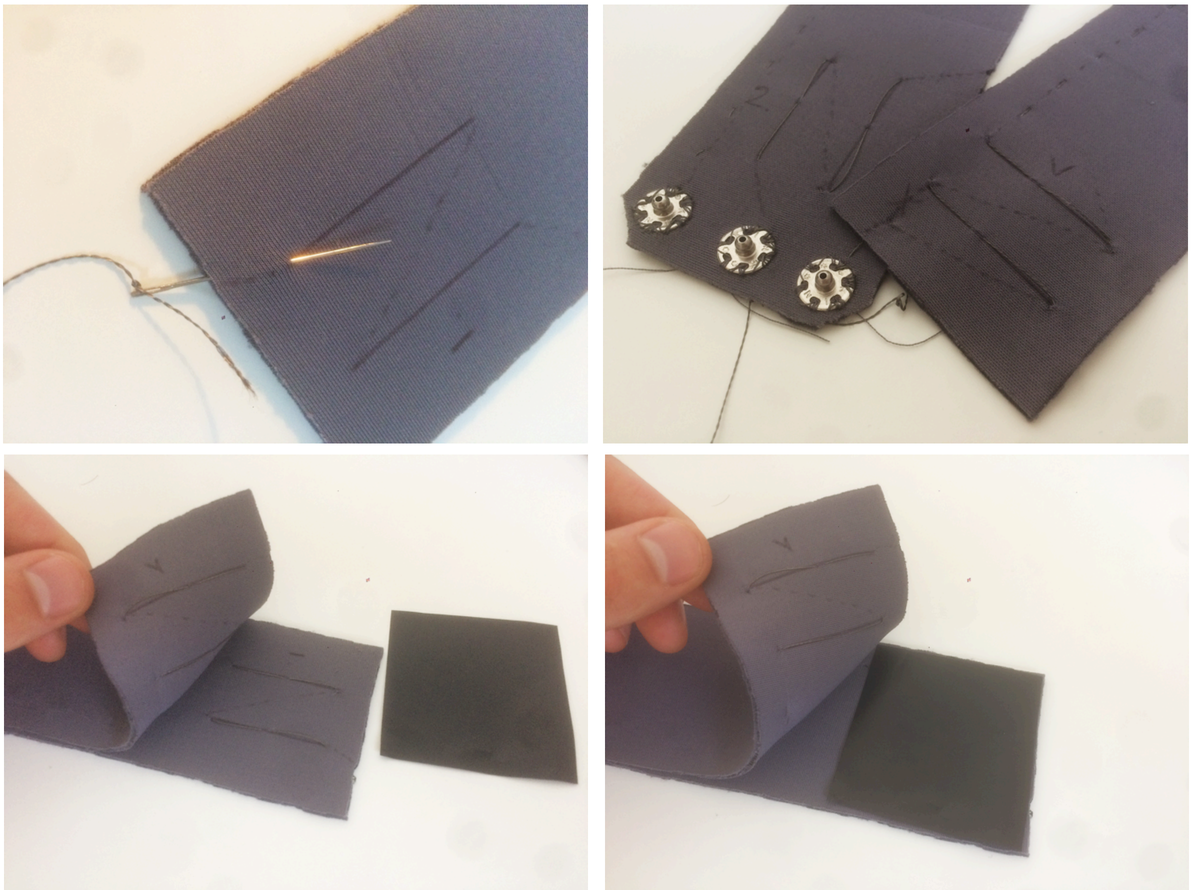
Touching/Feeling

Presented at CASS multimedia festival, KABK, May 2019

This installation consists of an A4-sized wooden plank resting on two rectangular foam pieces. Fabric sensors under all four corners measure pressure and use this to control amplitudes of four sine waves synthesized by a Teensy microcontroller. The combined audio signal is used to vibrate the wood through a transducer attached to the bottom side of the plank.

By touching the plank, or pressing down on it, downwards motion of the plank gets transmitted through the foam to pressure on the sensors on all four corner. The more one touches towards a corner of a plank, the bigger the difference between that sensor and the three other ones. When touching the middle area of the plank, all four corners receive a similar pressure.

The pressure sensors consist of two layers of neoprene fabric with a layer of velostat in between. Exposed conductive threads on either inner side of the neoprene (shown on next page, top row) are separated by the velostat (shown on next page, bottom row) to create pressure sensors under each corner of the plank. One side of exposed thread in each sensor is connected to the voltage source of the Teensy, the other sides go through pull-up resistors to four analog inputs on the Teensy. The software on the Teensy maps the fours streams of pressure data from each corner to the amplitudes of four individual sine waves. The frequency of the sine waves has been set to match the natural resonances of the plank, to maximally activate it.



Making of a fabric pressure sensor using conductive thread and velostat as a variable resistor. Metal snaps (top right) make for easy connections with alligator clips.

Wood

Not publically presented, 2019

A wooden board, hanging by fishing wire from a wooden frame, is brought into oscillation by feeding back a contact microphone to a surface transducer attached to the same side. By dampening certain areas of the wood, bending it, or tapping on it, the feedback can be controlled. The microphone (AKG C411 PP) is attached with adhesive putty, and the transducer with double-sided tape. These bonds were chosen over screws as they do not rattle as much and slightly dampen noise and high frequencies.

The signal from the microphone is fed through a series of compressors and equalizers in Ableton Live and then amplified through the transducer. The chain has been set up to create a stable tone of feedback when it hangs freely. No sensors are used in this piece; the performer only has control by accessing the vibrating structure.

Hoops

'Wichelroede' presented at CASS concert, KABK, Februari 2020

A linen fabric is stretched in an embroidery hoop to create a membrane with surface tension. A contact microphone is attached with hot glue to the center of the bottom side of the fabric. Coils wrapped from enameled copper wire are embroidered in certain places of the stretched fabric, with the wire ends attached to an amplifier. Sound form the contact microphone is received in software, processed digitally, and the resulting signal is sent out to the amplifier. The electric signal running through the coil becomes magnetized. When a magnet is held over the coil(s) the electromagnetic force causes the audio signal to become movement. Since the coil and the microphone are attached to the same surface, vibrations from the coil get picked up and re-amplified by the coil, as long as a magnet is held near it.

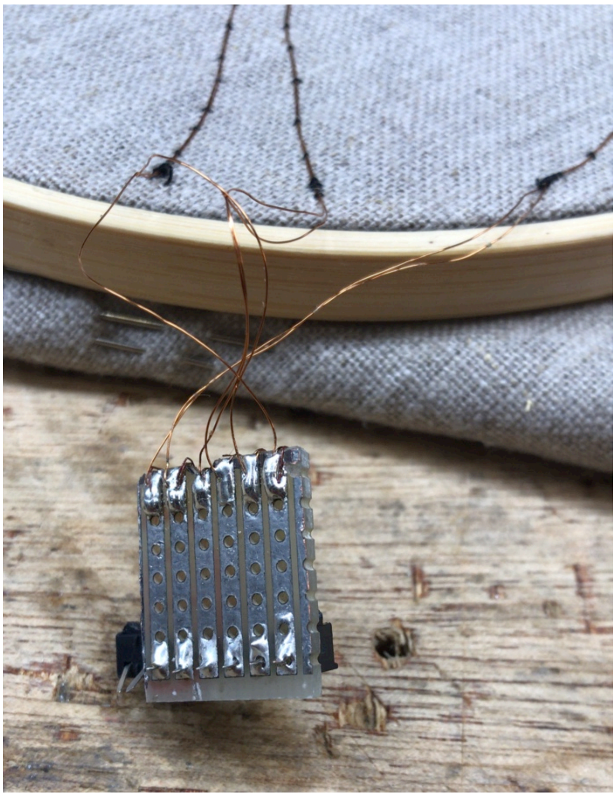
Sensors embroidered onto the fabric surface are made from conductive thread, velostat, conductive fabric, and regular embroidery thread, shown on the next pages.

The digital code has taken various forms, in Ableton Live, Max/MSP, and most recently Supercollider. All versions followed a same general implementation of compression, equalization, and amplification, to allow for stable, performable feedback to emerge through the fabric, coils & contact microphone. The latest version in Supercollider implements a granular delay engine controlled by the embroidered sensors.

Details of embroidered pressure sensors around a coil on the large hoop.

Embroidered sensors on small hoop.
Top left: conductive thread embroidered (couching stitch) following sensor design drawn on fabric.
Top right: pieces of velostat cut to match the four sensor shapes.
Bottom: sensors covered in embroiderey.
Not shown: conductive thread on top of velostat, which connects to Teensy's analog inputs.

Embroidered sensors on large hoop.
Top left: exposed conductive thread on fabric surface.
Top right: velostat cut to shape for two sensors.
Bottom left: conductive fabric cut to shape, left piece lightly sewn in place.
Bottom right: left sensor covered in embroidery, isolating the conductive materials.

Small Hoop details:
Left: conductive thread – jumper wire connection. **Right**: Coil – amplifier wire connection