Chapter 9
Embodied Musical Interaction

Body Physiology, Cross Modality, and Sonic Experience

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Abstract Music is a natural partner to human-computer interaction, offering tasks and use cases for novel forms of interaction. The richness of the relationship between a performer and their instrument in expressive musical performance can provide valuable insight to human-computer interaction (HCI) researchers interested in applying these forms of deep interaction to other fields. Despite the longstanding connection between music and HCI, it is not an automatic one, and its history arguably points to as many differences as it does overlaps. Music research and HCI research both encompass broad issues, and utilize a wide range of methods. In this chapter I discuss how the concept of embodied interaction can be one way to think about music interaction. I propose how the three "paradigms" of HCI and three design accounts from the interaction design literature can serve as a lens through which to consider types of music HCI. I use this conceptual framework to discuss three different musical projects—Haptic Wave, Form Follows Sound, and BioMuse.

9.1 Introduction

The increasing ubiquity of digital technology in all aspects of music making and listening causes us to reflect on what we mean by music interaction. Since the commercial deployment of digital audio in the 1980s with the CD, most musical recording and music listening entails some form of interaction with the computer. If music production and consumption involve computing as a matter of course, one might argue that all music today is some form of music-computer interaction.

In this chapter, I will draw upon the history of HCI and interaction design as a lens through which to look at different forms of musical human-machine interaction. I introduce the notion of embodied interaction that, beyond being just corporeal, is phenomenological and participative. Section 9.2 goes on to retrace a history of HCI and draws parallels with the development of electronic and computer music. I then introduce three paradigms, or "waves" of HCI and three styles of design practice,

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and describe computer music and sonic interaction design in those terms. Section 9.4 presents three projects: a haptic audio editor, a sound design workshop series, and the musical use of physiological signals. In the discussion section I analyze these projects in terms of the interaction framework established in the previous sections. I finish with concluding remarks.

9.2 Interaction Paradigms and Music

9.2.1 A Brief History of Interaction

In his foundational text, "Where the Action Is", Paul Dourish establishes the principles of embodied human-computer interaction (Dourish 2004). He retraces the history of human interaction with technological information systems to arrive at a definition of embodied interaction. I will use this to contextualize and situate the different forms music research can take with and within HCI. Dourish begins by identifying four broad stages of interaction: *electrical, symbolic, textual, and graphical*, leading to the forms of tangible and social interaction we have today. His prescience is noteworthy given that he was beginning to formulate these ideas in the late 1990s.

Electrical interaction describes information processing that engages directly with electrical circuitry in hardware. This refers to logic systems realized as cascading series of switches, valve tubes, resistors, capacitors, and transistors that route and modulate electrical current directly. Logic is implemented in circuit wiring, providing the source of the oft-used term, "hardwired".

Symbolic interaction refers to information processing on early computers where the syntax of interaction was dictated by the machine's binary states, and distinct memory banks formed the basis of conditional logical branching structures. This gave rise to the term "machine language". Interfacing with the machine took the form of punch cards that read in binary sequences based on the patterns of holes on a cardboard rectangle. Two types of cards differentiated data from control. Control would be the program logic of operations where the data cards stored binary representations of the information to be processed.

Textual interaction remains familiar to this day in the command line interface of a computer terminal. Machine functions are abstracted in human language-like commands and permit an interactive loop—a putative dialogue with the machine. A grammar of interaction emerges, allowing complex logical operations such as loops, conditions, and patterns.

The *graphical interaction* based on the desktop metaphor that we today take for granted emerged from research labs in the 1970s to bring with it a revolution in the ease-of-use of personal computing in the 1980s. Graphical representations allow the use of the computer screen as a two-dimensional space for visual interaction rather than the one-dimensional stream of textual characters. This supports forms of *direct manipulation* (Hutchins et al. 1985; Shneiderman 1982) to select and move screen elements via a cursor with pointing devices like the mouse, and the creation of skeuomorphic interface elements where onscreen representations mimicked objects from the physical world such as buttons and switches. This skeuomorphism is the basis of the metaphors underlying graphical user interfaces (GUI).

Following his historical account of HCI, Dourish continues by predicting the further evolution of modes of interaction beyond textual and graphical interaction, towards what he calls tangible and social interaction. Along with Mark Weiser's seminal "Computer for the 21st Century" where he imagines the disappearance of the computer and the rise of ubiquitous computing (Weiser 1991), Dourish imagined the possibilities of distributed computation where objects in the everyday world were endowed with computational power (Dourish 2004). Weiser and Dourish imagined that interaction would take place in a tangible manner through physical artefacts. The fact that these artefacts were objects of everyday life dispersed in the physical world of our daily lives meant that this tangible interaction was also necessarily a social interaction.

Today these visions seem almost quaint—they have become reality, with the many connected devices and social media with which we carry out our lives. The principles of tangible and social interaction with ubiquitous computing form the concepts and technologies underlying the Internet of Things (IoT).

Tangible and social interactions, for Dourish create the context and conditions that define embodied interaction. They implore that we incorporate social understanding into the design of interaction itself, to allow that social situations influence activities carried out on technological systems. Embodied interaction should therefore parallel and accompany the ways we experience the everyday world. It should not require planning and instead facilitate spontaneous interaction. Embodiment, seen in this light, does not just describe the materialization of computing, nor does it refer only to the implication of the human body in interaction. Embodiment denotes forms of participation, and the settings in which interactions occur. It considers activity in concrete, and not abstract terms, and recognizes the ways in which the artefacts of daily interaction play different roles in different contexts and situations. Dourish draws upon the philosophy of phenomenology of Heidegger to ask whether interfaces are the object of attention of whether they become transparent in facilitating an interaction.

9.2.2 Musical Parallels to the History of HCI

Following Dourish's four historical eras of human-machine interaction, I propose the following parallels in the development of music technology. We can think of electrical interaction as the circuits of analogue modular synthesizers. Musical processes and compositions are created by wiring together oscillators, filters, and function generators. By using removable cables patched into sockets, different structures could be quickly realized, leading to the term, "patch", referring to a wiring configuration.[1] Note that this term remains with us today in graphical music representations discussed below.

Symbolic interaction and textual interaction in computer music are arguably inverted in time. The invention of computer music came through the programming of computer systems in the 1960s by Max Mathews to generate data which could be converted, via a digital-analogue convertor, to sound (Mathews 1963). This consisted of writing text instructions to generate, mathematically, a sequence of data representing a periodic audio waveform. A series of computer music programming languages followed to allow the synthesis of increasingly sophisticated sound, and their organization through compositional structures. The early languages include Music V by Mathews (1963) and Csound (Vercoe 1996), and today remain remarkably similar in textual computer music synthesis and composition languages including SuperCollider, ChucK, and others (McCartney 2002; Wang et al. 2003).

Symbolic interaction, directly in the language of the digital music machine, came as advances in computational processing made real time synthesis possible. While the textual interaction of the programming languages above today allow real time performance and the practice of "live coding", these languages originally required compilation and the offline rendering of a sound file. The advent of dedicated signal processing chips in the 1980s permitted calculation of sound synthesis as fast as it was needed to play in time, but were constrained to running on dedicated chips optimized for direct data processing in simple operations of adding, multiplying, and moving of binary data across shift registers. These signal processing chips did not have an operating system layer nor compilers or interpreters to process textual programming languages. Programming digital signal processing (DSP) consisted of interacting with the machine in its terms through assembly language, which could be directly mapped to machine code (Strawn 1988).

Music was an application area that very early on benefitted from innovations of the graphical user interface. The metaphor paradigm of graphical interaction permitted multiple metaphors from analogue sound synthesis as well as recording studios to be implemented in end user music software. The signal patching metaphor of analogue synthesizers could be represented on the computer screen in a data flow model of boxes representing musical functions, interconnected by virtual wires onscreen, to make patches in software such as Pure Data (Puckette 1997) and MaxMSP (Zicarelli 2002).

The mixing console metaphor brought with it visually rich interfaces and representation of controls via graphical faders and knobs. The tape metaphor brought the notion of transport controls (stop, play, fast forward, rewind) that could be represented onscreen as virtual buttons. These representations are a form of skeuomorphism, and use familiar real world references to permit direct manipulation of screen elements. They allow the musician to use their tacit knowledge and visceral memory of a recording studio to quickly become familiar with the sophisticated functions of computer music production tools through direct manipulation. As Dourish notes, this

[1] An exemplar of the emergent complexity afforded by analogue synthesizer patching is heard in Douglas Leedy's "Entropical Paradise" (Strange 1983).

evolution in interaction, from electrical through symbolic and textual to graphical, increasingly made computer technology not just more accessible, but integrated into daily life. It is through this same graphical evolution that computer music—which was a specialist practice in the times of symbolic and textual interaction—became integrated into the digital and audio workstations and production tools now prevalent in common musical practice. Can we extend these parallels between the history of HCI and of electronic and computer music to look at the current and future development of embodied music HCI? Can we apply the theory of embodied interaction to inform the design of digital musical instruments (DMI)?

9.3 Contexts and Paradigms of Interaction

The context in which interaction takes place is a fundamental factor in embodied interaction. This includes the social situations as well as the task spaces in which technology is called on to support interaction. Alongside the scientific advancement of human-machine interaction research, the field of HCI is a highly reflexive practice that looks critically at the evolving contexts in which the fruits of the research take place. In this reflective self-examination of the field, interaction researchers have identified three paradigms, or "waves" of HCI. Design theorists have proposed different styles of design practice based on the ways that context can impinge upon design goals.

The diversity of ways in which music takes place can also be considered by thinking of the contexts in which it happens. Music performed in a concert, being practiced at home, or listened to on a car stereo are all different possible contexts for a single musical work. Music, as a cultural practice that draws upon technique and technology, includes critique and self-examination as a natural part of its creative and developmental processes. The evolution of paradigms of HCI that will be presented below reflexivity as a driving force in the evolution of a research discipline. Can we apply the self-reflexive practices from interaction design to the naturally self-critical nature of music as a potential method by which we can consider the social and human significance of music interaction research?

9.3.1 Third Wave HCI

Bødker identifies three *waves* of HCI (Bødker 2006, 2015), while Harrison, Tatar, and Sengers refer to three corresponding *paradigms* (Harrison et al. 2007). The first wave of HCI was based on cognitive science paradigms to study human factors. It focused on the human being as a subject to be studied through formal methods and systematic testing to arrive at models of interaction. Second Wave HCI, according to Liam Bannon, moved "from human factors to human actors" (Bannon 1995). This phase focused on work place settings, studying group work in different communities of practice (Wenger 1998). Action was considered to be situated (Suchman 1987), and HCI assimilated social science techniques of ethnography and participation into user-centric design methods. If first wave HCI was engineering focused and design-centric, where designers invented new interfaces to be tested in domain specific use, the second wave shifted focus to the user, putting them at the center of a design process where interaction designers became sensitive to user needs in workplace contexts. In third wave HCI, the use cases and application types broadened to include leisure and everyday settings as technology spread from the workplace to domestic, social, and cultural contexts. Focus has increasingly shifted from the task performance optimization of first wave, beyond supporting users in the workplace in the second wave, to finding ways to study experience and meaning-making. According to Bill Gaver, an early researcher of sonic interaction (Gaver 1989) and leading exponent of third wave methods such as cultural probes (Gaver et al. 1999), "people's use of technologies increasingly needs to be understood as situated in their individual lives, values, histories and social circumstances. It understands that computation is not merely functional, but has aesthetic, emotional and cultural dimensions as well" (Gaver 2014).

9.3.2 Three Accounts of Interaction Design

In addition to context, the approach to the design of interaction is an important element in HCI. Interaction design might involve elements of industrial design (of devices), graphics design (of visual interfaces) or conceptual design (of scenarios and situations). Fallman discusses HCI from a design perspective, in what he terms "design oriented HCI." He identifies three "accounts", or approaches to design in HCI that differ depending on the goals and objectives of the imagined interaction. He calls these three approaches the *conservative*, *pragmatic*, and *romantic* accounts (Fallman 2003). He discusses how elements in the interaction design process differ for each type of design account in key areas such as the roles of the designer, definition of the problem, process, and outcome. These design accounts are summarized in Table 9.1.

In the conservative account, design is a rational, scientific or engineering endeavor, drawing on systems theory. Optimization and the design of a "better" solution are seen as goals. In this account the designer is an information processor, the problem must be clearly defined, and the outcome is objective knowledge.

In the pragmatic account, the role of design, and by consequence the designer, is to be engaged in the situation surrounding the task at hand. Design is contextual, and takes place in relation to place, history, and identity. This situates the design act in a world already full of people and things, unlike the rational compartmentalization of the conservative account. The designer in this case is reflective, goals are relational, and outcomes are driven by dialogue and are embedded in the surrounding world.

The romantic account gives prominence to the designer as a master. They are visionary and imaginative and are accorded latitude for caprice in creation. In this approach to design, the actual definition of the problem is ultimately subordinate to

Table 9.1 Fallman's three design accounts (Fallman 2003)

	Conservative	Pragmatic	Romantic
Designer	Information processor	Bricoleur	Artist
Problem	Ill-defined, to be defined	Unique to the situation	Subordinate to the final product
Product	Result of the process	Integrated in the world	Artwork
Process	Rational and transparent	Reflective dialogue	Opaque
Knowledge	Guidelines, scientific principles	Experience, ways of problem solving	Craft, creative imagination
Role model	Natural sciences, engineering	Social sciences	Poetry

expected brilliance of the final outcome, with the process leading to its production opaque or even magical. Fallman does not make value judgments and does not elevate one approach to design over another.

9.3.3 Interaction Paradigms and Music

While the innately cultural nature of music might make it seem that music interaction would most sensibly constitute forms of third wave HCI, the range of tasks carried out in musical practice, from composing to practicing and performing, from studying to producing, from listening to sharing, mean that that music HCI ultimately straddles all three paradigms, or waves, of human-computer interaction.

We can retrace the history of computer music through the lens of the three waves of HCI. Early computer music used formal methods of calculation to specify sound synthesis by mathematical means like the fast Fourier transform, used to carry out frequency analysis of sound. These techniques were used to analyze the timbre of traditional musical instruments (Risset and Mathews 1969) and to synthesize emulations of them by means of frequency modulation and physical modelling (Chowning 1973; Smith 1992). This approach to modelling and digitally emulating the existing world is consistent with the systematic engineering approaches of first wave HCI.

What could be called second wave musical HCI came with the application of increasingly powerful interaction techniques such as novel interfaces and real time signal processing to musical performance. The assumption of stage performance as the main means of musical dissemination can be considered parallel to a focus on workplace settings in second wave HCI. Much of the work in the field of

New Interfaces for Musical Expression (NIME) (Poupyrev et al. 2001) proposes new interfaces to be considered as musical instruments to be performed in concert settings. Even seemingly radical departures, such as the formation of laptop orchestras and practices such as live coding, ultimately adhere to traditional performance, and therefore "workplace" contexts. That these novel approaches to music making tapped communities of practice—individual laptop musicians coming together to form an "orchestra" are also consistent with the principles of second wave HCI.

If these novel forms of musical interaction still only correspond to second wave HCI, what is required for music interaction to take on the situated, experiential character of third wave HCI? One could argue that music itself, despite being an aesthetic and cultural activity, may, as a structured, often hierarchical, codified model of cultural production, actually constrain musical interaction from truly seeping into everyday life. Seen in this light, we might consider research in sonic interaction design (Franinović and Serafin 2013) as liberating sound from traditional constraints of music to investigate the place of sound, and our interaction with sound, in everyday life, as having these situational, experiential qualities. Could it be, then, that an ostensibly non-musical interaction with sound be the springboard towards a third wave music HCI?

9.4 Case Studies

In the following sections, I will present three research projects that address the question of embodied musical interaction from different perspectives. They cover a range of ways to look at the question of embodiment, from the creation of new musical instruments, to accessibility tools, to the study of auditory experience. As much as they are sound and music projects, they have been published in the HCI literature, pointing out the interest of musical practice as fertile application areas where questions of haptic and physiological interaction and user experience can be explored in depth. As such, they draw upon the different paradigms of HCI, and can be described in terms of Fallman's design approaches. Seen together, they demonstrate the diversity of perspectives from which we can think about embodied music HCI.

9.4.1 Haptic Wave

The Haptic Wave is an interface that renders sound tangible. It was originally designed in a project studying design patterns in cross-modal interaction (Metatla et al. 2016), where we studied the mapping information from one sensory modality to another. In the case of the Haptic Wave, we were interested in mapping audio directly to the haptic domain bypassing an intervening visual representation. It was developed in collaboration with a group of visually impaired musicians and producers as a means to overcome the highly visual nature of music production on computer-based digital

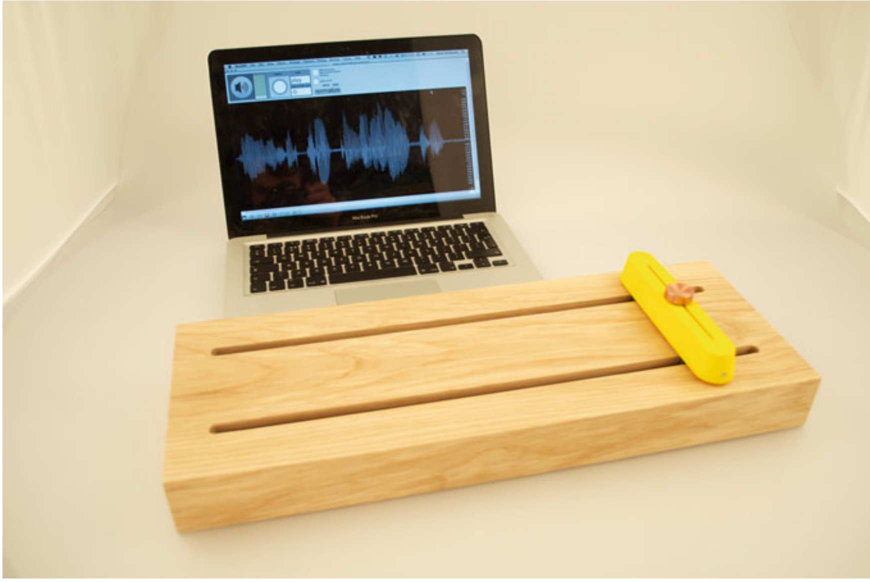

Fig. 9.1 The Haptic Wave cross-modal audio waveform editing interface

audio workstations (DAW). The graphical user interfaces (GUI) of these systems use skeuomorphic metaphors of studio mixing consoles, and visual representations of sound in graphical waveform displays inaccessible to visually impaired users. The Haptic Wave presented audio for editing in a tactile form by creating a two dimensional physical plane where sound amplitude was retraced by a motorized slider's vertical movements. By displacing the slider structure left and right, the user is able to scan in time through the sound, and feel its amplitude through up and down movements of the slider tip (Tanaka and Parkinson 2016) (Fig. 9.1).

This project ostensibly represented an example of second wave HCI—it took the workplace situation of music production and audio editing as the context of study, and aimed to provide a specific set of users—visually impaired musicians—an improved set of tools by which they could be fully productive. The Haptic Wave was developed using participatory techniques as a way of understanding the needs of our users (Parkinson et al. 2015). As musicians, we understood the workplace context under study, but as sighted people, we had no idea what challenges visual impairment posed for our users to be productive in these environments. Meanwhile, we were able to introduce to our users concepts of cross-modal mapping and multimodal interaction, and innovative technologies of haptic interaction. Through a process of user-centered design, we put in place a series of activities including interviews, workshops, and brainstorming sessions, to explore and prototype interaction ideas to make audio waveform editing less visually dependent.

The result was the iterative refinement of the Haptic Wave design and its deployment and evaluation in real world settings where the device was integrated into professional recording studios and used by different kinds of musicians and producers who were all visually impaired. Alongside the second wave HCI paradigm, the design approach was a pragmatic one. Following Fallman's design accounts (Table 9.1) the designers in this case were *bricoleurs*—tinkerers or hackers. The first iteration created by a well-known tinkerer/musician, and the definitive version by an industrial designer from Bill Gaver's Interaction Research Studio.[2] The product was an outcome of a dialogue in a reflective, conversational process. The knowledge generated resulted not just in a better interface, but in methods for carrying out design explorations with visually impaired users.

Despite this clear pragmatic orientation, there are nonetheless elements of both conservative and romantic design that contributed to the Haptic Wave project. There was a clear, rational process in identifying and configuring technologies of haptic display of audio data, and engineering prowess exercised by the hardware developer to produce a high precision horizontal sliding bed. This engineering contributed not just to the smooth operation of the device, but created the right "feel" for the interface. In this way, the conservative design account fed into and encouraged a romantic account, where other elements of feel (as well as look) were picked up by the industrial designer in a careful selection of materials (wood, copper, plastic) with which to fabricate the device. The choices were not solely aesthetic, but also aided in differentiating, by tactile temperature of each surface, different functions and parts of the device to the non-sighted user.

Surprisingly, the Haptic Wave received enthusiastic responses from sighted users. This was an unexpected turn, coming from a different type of user than the original user group with whom we had co-designed the device. Sighted musicians expressed an interest in using the device as a way to free themselves from the computer screen while editing or performing music. For example, a DJ saw potential in using the Haptic Wave to scrub sounds physically, instead of using the mouse and computer screen onstage in clubs where stage lights made screens difficult to see. Or, without a screen in front of him, he thought he could have a more direct connection with his audience. In this unexpected response, not intended in the original design, the device that had gone through a pragmatic or even conservative design process seemed to unlock and inspire imagination as a romantic interface device. A second wave HCI interface device for sound editing in this way inspired imagination as an expressive instrument for third wave music HCI. In this way the Haptic Wave was perceived by a new set of users as compelling beyond its original workplace context (the recording studio) to enable embodied musical interaction in social, cultural settings.

9.4.2 Form Follows Sound

Form Follows Sound (FFS) was a collaboration between our research group in gestural music at Goldsmiths, University of London and Parsons New School of Design (Caramiaux et al. 2015a). We used classical user-centered design methods from sec-

[2] https://www.gold.ac.uk/interaction/.

Fig. 9.2 Form Follows Sound sonic interaction scenario building workshop

ond wave HCI to explore embodied relationships we have with sound in everyday life. The hypothesis was that we internalize our encounters with sound, and that these encounters can take on corporeal and visceral aspects. However, the visual dominance of society does not provide us with ways to adequately describe encounters with sound, especially for people without training in audio engineering or music. By creating a set of workshop activities bolstered by gestural interactive music technologies, we hoped to create settings in which people without prior experience in embodied interaction could tune into sound in the everyday, and to convey the significance of their own daily sonic experiences.

We devised a workshop plan that would take place over a 1 or 2 day program in groups of 10–15 participants. The workshop was carried out on four different occasions with diverse groups of people, in the UK, US, France, and Switzerland. Each iteration of the workshop allowed us to take lessons learned from the previous iteration to improve and fine-tune the workshop protocol. The workshop program consisted of two stages, *Ideation*, for brainstorming and idea generation and *Realization*, for prototyping interactions (Fig. 9.2).

9.4.2.1 Sonic Incidents and Sonic Affordance

The Ideation stage took place as group activities on pencil and paper, without any digital technologies. In this stage, we used ethnomethodology and design brainstorming techniques to get participants to think about sound in the everyday. In this phase, we drew upon the critical incident, a technique from psychology (Flanagan 1954) that has been applied in HCI research (Mackay 2004). The technique incites subjects to reflect on their daily life from the past days to recall moments that stood out. It encourages the subject to reflect on why that moment distinguished itself from the banal to become an incident, and how it affected them. We asked workshop participants to focus on moments in the recent everyday where they remembered the sound, and asked them to reflect on the visceral response they had to that sound. We termed this the *sonic incident*.

After sharing their sonic incidents, we asked participants to sketch out the scenario surrounding that moment. These sketches took on the form of storyboards (sequences of cartoon-like frames borrowed from film production). These storyboards recounted the story, schematized the incident as an interaction with sound, and extended it towards an imaginary agency one could have with the sound. For the latter, we encouraged the participants to think about how they might imagine producing the sound, instead of beholding the sound. In this way, we took a sonic incident, and instead of it being something that "happened", thought of it in terms of an interaction the person "made happen".

In the Realization phase of the workshop, the storyboards from the Ideation phase became interaction scenarios to be prototyped. We introduced a set of sensors to capture movement and gesture, along with a piece of software built in the lab, the Gesture-Sound Toolkit, as a user-friendly way to connect these sensors to the manipulation of sound. With the sensors and the software toolkit, workshop participants were provided the means to create sonic interaction prototypes to "enact" the incidents from their storyboards. Consistent with the participatory group work, workshop participants worked on each other's incidents, sometimes recombining incidents to make abstracted, imaginary scenarios. The resulting prototypes were presented to the others in the group in the form of a playful skit.

By moving from "sound happening" to "making sound happen", we were interested in studying the effect the sonic incident had on each person. We were interested in corporeal response not just as a reflex reaction, but also as potential for action on the part of the subject in his or her environment. We were inspired by environmental psychologist J. J. Gibson's notion of *affordance* that describes characteristics of the environment that invite action on the part of the subject (Gibson 1986). Gibson uses his theory of affordances to describe relationships we have with the physical world, through our visual perception of it and as a function of the relationships of scale between environment and subject. So for Gibson, a mailbox may afford a pulling action to open it, but only when we perceive it from an angle where its door and handle are visible. A chair may afford sitting for a human, but at its scale, would afford jumping up upon for a smaller animal like a cat. We wanted to look at ways that sounds in our environment might invite some kind of human action and in this way explore the possibility of *sonic affordance*.

9.4.2.2 Embodied Sonic Interaction

The participatory design activities in Form Follows Sound follow a classical second wave HCI methodology. However, by studying the occurrence of sound in the everyday, we brought this investigation into third wave contexts. Had we encapsulated the interactive sound technologies in a form that participants could have taken out of the workshop back home to the very environments in which their sonic incidents originally took place, we could have completed the third wave research loop. From a design perspective, we might ask whether the storyboarding and prototyping methods were examples of pragmatic design, or whether their use to tell and realize personal stories made them examples of romantic design. Given that the design of the interaction was not ever meant to "be" anything—neither a product nor an instrument—the prototype served as a trigger for the imagination, as a way to work out the corporeal affordances of sound that we encounter. In this sense, we might say that the prototyping activity was a form of romantic, speculative design.

The Gesture-Sound Toolkit made music interaction techniques from NIME available to non-specialists in this design exploration. It facilitated the integration of sensors as a means to capture body movement. The audio playback part of the software provided workshop participants ways to quickly author interactive sound to illustrate their sonic incident—either by imitating the sound through vocalization, or by quickly accessing samples of recorded sound from open source online databases (Akkermans et al. 2011). Different modules, or building blocks in the software that could be rearranged by the users, enabled them to then map incoming gesture from the sensors to articulating some aspect of the sound playback. Gestures might be classified by machine learning classifiers to trigger different sounds depending on which sound was recognized, or in a regression algorithm associate continuous incoming gesture to some aspect of sound morphology such as frequency or amplitude, allowing an embodied sculpting of sound. These are classic techniques in digital musical instrument building and composition, here taken out of a musical context to facilitate the exploration of potential embodied interactions with everyday sound. In this sense, by studying our embodied relationships with sound in the everyday, the FFS research situated NIME technologies within a third wave HCI context. Sensors and machine learning, typically the domain of conservative or pragmatic design, were made user-friendly through the Gesture-Sound Toolkit to facilitate romantic design amongst workshop participants.

9.4.3 BioMuse

Physiological interfaces would at first seem to represent the pinnacle of embodied interaction and therefore for embodied music HCI. However there are many approaches to exploiting biosignals in music, from the barely visible performer actions in brainwave works such as Alvin Lucier's seminal *Music for Solo Performer* (Lucier 1982), to a more gestural use of muscle electromyogram (Donnarumma 2016;

Fig. 9.3 The author performing an EMG instrument in concert, 2017 (credit ZKM ONUK)

Tanaka 2017) (Fig. 9.3), to audience monitoring using galvanic skin response (Knapp et al. 2009; Lyon et al. 2014), or electrical muscle stimulation (Lopes and Baudisch 2013; Smith 2005).[3] These different approaches to coupling body physiology and music highlight different interaction modes, use contexts, and design accounts.

The most common means to detect muscle tension is by way of the electromyogram (EMG) signal, a series of microvolt electrical impulses generated by the nervous system to command and cause muscle contraction. Technologies of interfacing to the human body via the EMG signal have emerged from the biomedical sphere to be widely available today in the DIY community with systems like the Bitalino,[4] and even in consumer products for multimodal, hands free interaction (da Silva et al. 2014). These products build upon interaction research with the EMG (Saponas et al. 2010) that sought to make such signals from the body practical for applications in HCI. The EMG remains a novel interface with vast expressive potential for music. There is a gap between the relatively banal end-user interactions of commercial products and the potential for expressive musicality imagined by musicians. What are, then, the barriers to generalizing the expressive potential of the EMG in music HCI? Which modes of interaction or design accounts might they represent and how might they differ from the use of EMG in biomedical or computer interface contexts?

[3] See also Chap. 11 in this volume for an educational application of brainwave biosignals (Yuksel 2019).

[4] http://bitalino.com.

9.4.3.1 Gesture Vocabularies

By extending personal musical practice through research to glean insight on generalized interaction, we have encountered three types of challenges: at the level of gesture definition, the user's ability to reproduce gesture, and techniques we have for data analysis. These challenges point to a fundamental first wave HCI, human factors perspective in arriving at robust interaction using the EMG.

The first step in any study of gesture with multiple users is to create a gesture vocabulary. This establishes what actions the subject executes, and establishes the range and variety of different gesture primitives. Although we may already have an idea of what each gesture might signify, the "what" of the gesture is initially independent of the "what" of its meaning. A number of standard gesture sets exist in the biomedical literature (Phinyomark et al. 2012). These datasets have been conceived to demonstrate the different hand postures that result from activation of distinct muscle groups. The gestures making up these data sets are correspondingly named for the action required to perform them (Kaufmann et al. 2010). We can also think of sign language as a gesture set. While sign language exists as a rich set of gestures signifying phonemes and entire words, most hand gesture analysis techniques have focused on signs of individual letters in the 26-letter alphabet. While we describe gestures, which we assume to be dynamic time based trajectories, most of the gesture sets noted above in fact describe static postures.

The richness of the EMG goes beyond measuring steady state signals produced in fixed postural limb positions. The muscle articulation in the preparation and execution of a gesture to arrive at a target posture are of interest, and constitute the temporal evolution of body action that is potentially rich in musical expressivity. While "gestures" (in fact poses) in the biomedical literature are described by nouns that describe muscle exertion, in our work, we study the dynamic EMG trajectories in executing gestures and label them by verbs. In this way, we hope to capture the dynamic, time-based nature of musical performance.

9.4.3.2 Effort

Arriving at a satisfactory, intuitive, embodied interaction needs to address first wave HCI biophysical challenges. This creates non-trivial challenges in the specification and analysis of EMG in HCI contexts. These issues point to the need for a pragmatic design approach in which researchers work with users on ergonomics in actual use. This takes EMG interaction beyond the controlled environments of biomedical research—where extraneous limb movement can be constrained for the sake of the experiment—to the less controllable, chaotic situations of actual, real world musical performance.

Each person has a different relationship with their body, and the relationship of their body to the outside world. The strategies with which we control our bodies in physical activity, by use of our muscles, is highly personal. This notion of embodiment, seen through the sense of one's own body is experiential, and seemingly representative of third wave HCI approaches. Meanwhile, the measurement of physiological signals, and the specification of gesture for interactive or musical goals, point out the need to study human performance from a first wave perspective. We have worked with EMG sensing in expressive musical performance, and have tried to extract from that experience, potential modes of sonic interaction that could be useful to other musicians and even non-musical users (Caramiaux et al. 2015b). From a design account perspective, we might consider this an attempt to offer alternatives to a purely scientific, medical exploration of muscle gesture, by extending from conservative to romantic design exploration in expressive musical performance.

9.5 Discussion

The use of biosignals by artists provides an example of romantic design in the creation of performance systems using physiological signals. This includes my own work in the use of EMG as a means to turn the human body into a musical instrument (Tanaka 1993, 2012; Tanaka and Donnarumma 2018). Despite the rich artistic and scientific community spanning disciplines and history documented above, all of our respective work in this area is idiosyncratic and highly personal, and in this way, is ultimately romantic. When we try to capture and characterize, or generalize, the expressivity of these systems in the laboratory, we are confronted with first wave human factors issues such as gesture reproducibility and the forms of normativity and invariance imposed by machine learning classification algorithms. Machine learning can be useful as a means to fulfill pragmatic designs where classification is used to recognize basic gesture vocabularies. There is some scope to extend the expressive range of biosignal music using regression techniques to create gesture/sound that are potentially more expressive than traditional mapping and synthesis parameter interpolation. We are currently confronting the challenges of developing a robust first wave basis for physiological gesture analysis with which to push forward existing third wave bio-music applications.

The Haptic Wave represents a pragmatic design account in second wave HCI working with professional, visually impaired musicians and audio producers in their studios. However, once the device was finished, showing it to other users—sighted musicians—triggered romantic inspiration amongst these potential new users. This represented the kind of "unintended use" of technology often observed in qualitative, user-centric HCI research (Krischkowsky et al. 2016; Roedl et al. 2015). A third wave context was imagined by our "new" users, subverting an interface designed to enhance task performance in a specific user group, and transposing it to new uses onstage in musical performance. Certain design features of the Haptic Wave that were pragmatic—for example the use of different materials for different components of the device to allow perceived material temperature to guide a visually impaired user to different parts of the device she/he couldn't see—became a romantic design element of an attractive performance instrument constructed of wood, 3D printed plastics, and moving metallic parts, for our DJs. The cross-modal mapping of a visual audio waveform into the haptic domain was meant to rigorously exploit a sense modality available to our original users in order for them to more successfully be fully integrated into the professional music industry in which they worked. The haptic representation was re-interpreted by our sighted users beyond pure pragmatism and necessity to become an inspiring mode of interaction for them to imagine DJing and performing in cultural, third wave contexts.

If the Haptic Wave demonstrates an almost incidental or inadvertent transposition of a second wave device to third wave applications, Form Follows Sound represents the intentional adaptation of second wave NIME techniques for use in third wave everyday contexts. By presenting sensor-sound mapping and machine learning in an easy to use interface, the Gesture-Sound Toolkit became an enabling tool for third wave music HCI that supported users in sketching embodied sound interactions with which they could evoke and explore their everyday embodied sonic experiences.

Dourish contextualizes embodied interaction in the historical development of human-machine interaction. In arriving at a definition of embodied interaction, he notes that it does not just have to do with the embodiment of interfaces as objects, nor the simple solicitation of the body, but that embodiment has as much to do with experience which he describes using the philosophy of phenomenology, in what he calls "participative status." I propose that this reading of embodiment in technology is useful to us as we consider music as it becomes increasingly technologized. Will we lose the primacy of the body as we move from acoustic instruments to electronic music production tools? Does music listening on personal digital devices isolate us compared to the sociality inherent in shared amateur performance? A consideration of the social and technological aspects of embodiment will aid us in understanding the different possible modes of music HCI. With music being a fundamentally social and participatory activity, can we imagine creating new technologies of musical interaction inspired by this model of embodiment?

9.6 Conclusion

The three projects presented here represent the potential breadth of music HCI. While they at first seem very different, they nonetheless all adhere to the same vision, that a tangible, direct manipulation of sound can create forms of embodied musical interaction with rich artistic and social potential.

These projects studied digitally mediated musical interaction in performance, in work place settings, and in everyday life. They look at the potential of human interface technologies to improve audio task performance amongst the visually impaired, to enhance expressivity in computer music performance onstage, and to facilitate the understandings of our relationships with sound in the everyday. In this regard, they span the paradigms of first wave, second wave, and third wave HCI. They were produced with design approaches that were rich and multifarious, often representing multiple design accounts within a single project. In this sense, the conservative, pragmatic, and romantic design accounts are not exclusive, but useful ways to think about different aspects of any project, as design objectives shift to follow the evolution of a project.

Modes of interaction in the history of electronic and computer music broadly follow the history of interaction in HCI. This history is cumulative where electrical, symbolic, textual, and graphical interaction are seen in electronic music practices of modular synthesis, live coding, and graphical programming. The gesture sensors and haptic actuators used in the projects described here provide ways to capture visceral aspects that are fundamental in so much music, technological or not. Music, in this light, is seen as a form of enactivism (Maturana and Varela 1987) that is acted out in forms of engagement and musicking (Small 2011). These projects have studied music in relation to the body, performance, and sonic experience in everyday life. Together they encompass the social and participative qualities that comprise embodied interaction, and in doing, allow us to explore different aspects of what we might call embodied music HCI.

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