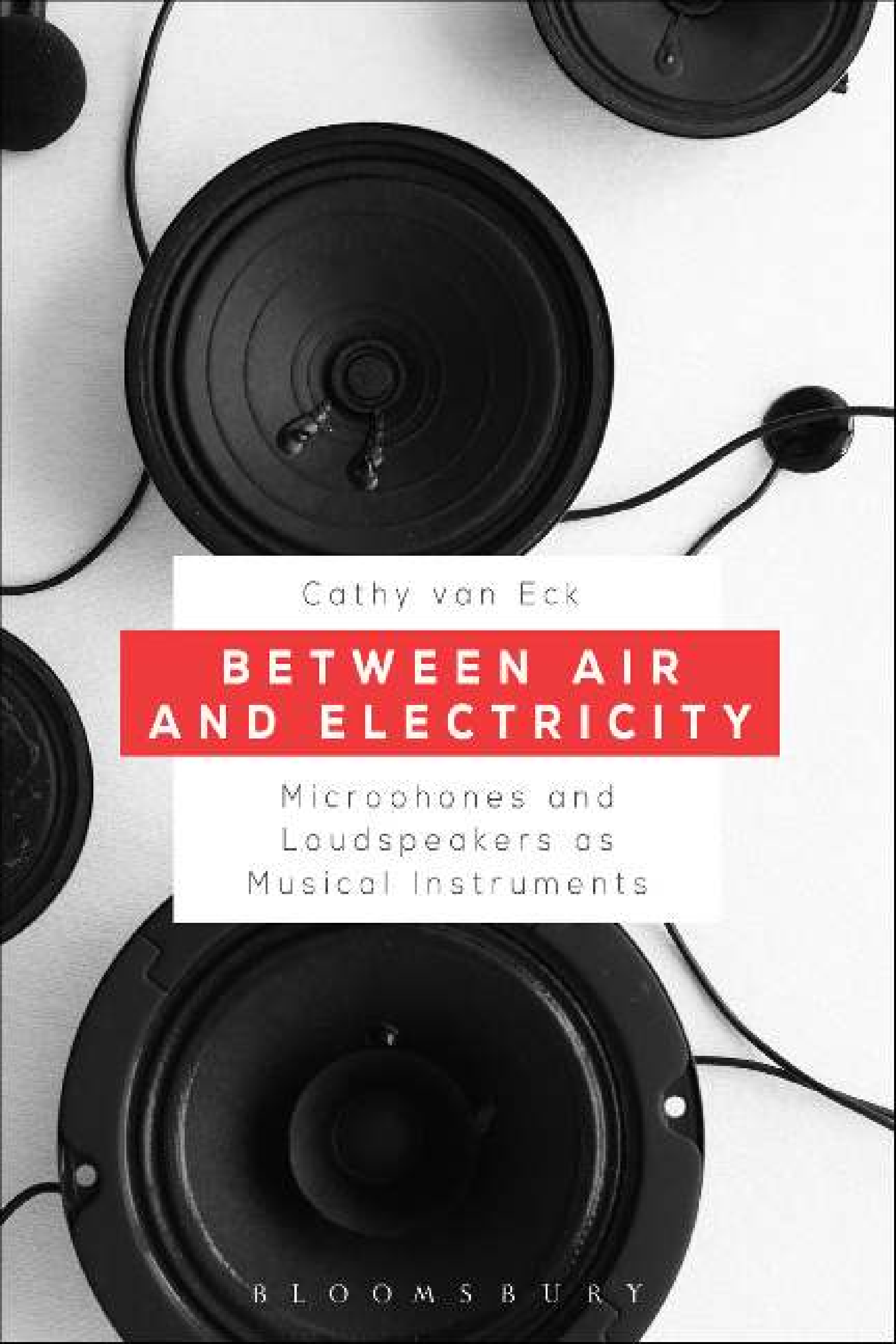

Cathy van Eck

BETWEEN AIR AND ELECTRICITY

Microphones and Loudspeakers as Musical Instruments

BLOOMSBURY

Between Air and Electricity

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Introduction

Are microphones and loudspeakers musical instruments?

This question is the starting point for my book *Between Air and Electricity* which tells the story of how microphones and loudspeakers have changed music over the past 100 years through artistic experiments and innovation. It is very common nowadays to have microphones and loudspeakers used on stage next to musicians and conventional musical instruments. One of the initial seeds of inspiration for my book was how these elements of a musical performance contrast with one another. The sound producing relationship between a gesticulating musician and a musical instrument is obvious. Even without knowing much about the violin or piano, it becomes immediately clear by hearing and seeing a violinist, what this person is doing and how the sound is changed according to her gestures. On the contrary, the sounds emitted by a loudspeaker can theoretically be any sound: a musical instrument such as a violin; environmental sounds such as the sea; or machines, such as car sounds. And what might have been originally a very soft sound whispered by a performer into a microphone might be diffused very loudly through loudspeakers. Besides, whereas the musician is also able to communicate visually with the audience, the microphone and loudspeaker on stage are just seemingly immovable devices, often painted black to remain as unnoticeable as possible.

Microphone and loudspeaker technology is omnipresent not only in music but as well in our everyday life. Here, also, these devices are often designed to remain invisible and sonically transparent; that is, 'inaudible' in the final sound result. We hardly seem to notice them anymore – how often are our voices transmitted through a telephone receiver, do we hear the latest news on the car radio, or are simply listening to music through our headphones? These are all microphones or loudspeakers. Microphones and loudspeakers are employed in almost all music we hear nowadays: to amplify the voices and electric guitars of a rock band, to facilitate the production of a 'perfect' recording of a symphony orchestra, to reproduce that recording in the living room, and as an essential component of many modes of presentation, from the Jamaican sound system to techno parties. All music has now become available everywhere and is available at any moment. This is in contrast to the way it had been in all music cultures before sound reproduction technology, which was created by musicians only for their own society and in its own specific context. Inventions such as the phonograph, radios and telephones – usually grouped under the term 'sound reproduction technology' – changed our relation to all sonic events in society. But the invention of microphones and loudspeakers using electricity for amplification particularly changed musical performances, since their quality of sound reproduction is ameliorated extensively in comparison to the horns used before. This made their sonic quality good enough not only for communicating speech through the telephone or reproducing well-known music through the radio but also attractive to composers and musicians who wanted to use these devices that were able to reproduce all kinds of sounds on stage.

I started the research for this book as a composer, and this is the main role I tried to keep during the whole process. Coming from instrumental music with written scores, I soon started to work with recorded and electronically produced sounds, and consequently I had to deal with these microphones and loudspeakers. What I remember of my early days using this technology is how different, not only visually but also sonically, the sound of live musicians playing instruments or loudspeakers is on stage. My first attempt to bring both together was by literally binding them together: the musicians were given a loudspeaker attached to their backs through which the live processed sounds of their instruments were diffused: my composition *Actions of Memory* (2004) was the result. As a result, I became interested in other compositions using microphones and loudspeakers in unconventional ways. Composers such as Karlheinz Stockhausen and David Tudor created their well-known compositions *Mikrophonie I* and *Rainforest*, respectively, from the desire to treat microphones and loudspeakers as musical instruments. To consider these devices as actively determining a musical performance similarly to how a common musical instrument determines a performance became my main research topic. I searched for compositional situations in which microphones and loudspeakers added their specific characteristics to the final composition, comparable to how musical instruments influence the resulting sound. This book thus takes the artistic use of the devices that bring air pressure waves (sound waves) into electricity and back as its central focus point. For this reason, it is entitled *Between Air and Electricity*. But the title of this book also refers to what is essential for human beings – air – and a common energy source for machines: electricity. Microphones and loudspeakers can be seen as the interface between human performers and listeners, and all kinds of electronic machines for sound shaping, such as synthesizers and computers. These devices processing electrical signals would not be able to communicate with mechanically produced sound without getting their input signal from microphones, and would remain silent, if their signal was not diffused through loudspeakers.

This book could easily have become a list of descriptions – and it would have been a very long list – of musical works in which microphones and loudspeakers are manipulated, often in very spectacular ways: pieces using microphones which have been frozen in ice, swallowed by performers, or catch the softest noise made by audience members; pieces in which loudspeakers are thrown through the air, hundreds of them covering walls and ceilings or drifting in lakes. Instead I arrived at different categories of interaction with microphones and loudspeakers, derived from my analyses of microphone and loudspeaker use by other artists and my own practice as a composer. These different categories are meant to be tools not only for analysing compositions but also for composing new pieces with microphones and loudspeakers.

As I outline in Chapter 3, acoustic feedback became the sound that was most intrinsic for me when using microphones and loudspeakers as sound shaping devices. Starting from a set-up causing a feedback sound, I analysed different ways of interacting with microphones and loudspeakers. By moving them, changing the material through which they vibrate, and position them at a specific place in the performance space, I could change this acoustic feedback. These three categories – movement, material and space – became my main categories for composing with microphones and loudspeakers and form the main trail I elaborate on in Chapter 4. After having broken down each of these three categories in another six possibilities, I started to look for suitable compositions as exemplary models for this way of interacting with microphones and loudspeakers. As a result, there were microphone and loudspeaker uses for which I could have numerous examples, as was the case for *moving loudspeakers*, which now focuses on works by Gordon Monahan and Annea Lockwood, and which does not mention works by Benoît Maubrey or Steffi Weissmann, both of whom also have a very interesting approaches towards this subject. Similar to this is the use of contact microphones for the development of new instruments, as described in *new instruments through amplification*. From each of several artists – for example, Alvin Lucier and Hugh Davies – I chose more than one composition, each for a different category. These artists have worked very intensively with microphones and loudspeakers, and someone such as Alvin Lucier has made so many fascinating works with microphones and loudspeakers that it would undoubtedly be possible to cover a whole book solely on his work with these devices. Some very famous pieces are omitted: the *Polytopes* by Iannis Xenakis, for example. Sometimes it was really difficult to find compositions or musical works that would fit a category, such as, for example, *acoustic feedback through objects*. Finally I found the piece *Nodalings* by Nicolas Collins as an example of this idea, but evidently the lack of compositions in this category made me doubt my analysis of microphone and loudspeaker use (or my lack of knowledge of the repertoire. Evidently there are still many pieces using microphones and loudspeakers I do not yet know). To try out for myself the possibilities of this category *acoustic feedback by objects*, I composed *Music Stands* (2011) for acoustic feedback through a note stand.

Over the years, by exploring these compositions, as I describe in Chapter 4, and through my own work as a composer, I realized that I had overseen an important aspect on the role microphones and loudspeakers play on stage as well. As a kind of basic introduction, I had analysed microphone and loudspeaker use in relation to musical instruments, resulting in four approaches: reproducing, supporting, generating and interacting. They are outlined in detail in Chapter 2. I had supposed that it would be only the interacting approach that would be of interest, since here, the microphones and loudspeakers are approached similarly to how musicians and composers approach musical instruments. I had to rethink how microphones and loudspeakers influence and form compositional ideas, and as a result in Chapter 5, I write what is unique considering composing for microphones and loudspeakers, in contrast to writing music for conventional musical instruments: they can switch their identity, since an electrical signal is 'causing' the sound. Therefore, relationships between the body movements of performers and the resulting sounds are not obligatory, as in conventional musical instrument practice, but can be themselves composed. I also have a look at recent developments in microphone and loudspeaker technology and what we might expect to change in the near future.

Besides trying out all the possibilities I describe in Chapters 4 and 5, over the last years I also tried to attend as many concerts as possible using microphones and loudspeakers as musical instruments. Many of the effects described in Chapters 4 and 5 can only be perceived well when listening live to them. In this way, this book can also be seen as a counterposition towards all music being produced for reproduction in the living room. Microphones and loudspeakers, developed for reproducing sound, cannot reproduce their own specific sound. Since these devices are active as sound shaping devices in the music discussed in this book, this music cannot be transmitted through a hi-fi system in the living room. Listening live to Alvin Lucier's *Nothing is real (strawberry fields forever)* makes one listen more attentively even to the softest sound from the loudspeaker in the small teapot. A live version of Luigi Nono's *Guai ai gelidi Mostri* reveals how differentiated spatial perception can be obtained by composing with microphones and loudspeakers, an important element of the composition which is completely lost when played through a two-channel stereo system in the living room. Considering pieces, such as Lynn Pook's *Aptium*, that use bone conduction for the transmission of sound instead of air pressure waves, any kind of sound recording is out of the question, because you have to have loudspeakers attached to your own body.

The first three chapters offer an introduction, contextualization, and history for these compositional methods. I localize the field of research in Chapter 1, focusing on changes in the aesthetics of listening during the twentieth century in relation to microphone and loudspeaker technology. Using the idea of a curtain as a metaphor, I compare several developments in music and technology that hide the sound source. I confront these technologies with radical sound works by Dick Raaijmakers that focus on making microphones and loudspeakers themselves audible and end up literally destroying them. Probably the most inspiring texts I have read on microphones and loudspeakers have been several by Dick Raaijmakers. His texts on microphones (Raaijmakers 2007, 316–335) and on loudspeakers (Raaijmakers 1971) both articulate outstanding ideas on the nature of these devices. His investigation of these devices portrays them in a unique way, expressing very original thoughts on this subject. Especially in Chapter 1, but also at several other moments, I will refer to Raaijmakers's ideas on softhearers (as he calls the microphone) and loudspeakers.

Chapter 2 gives an overview of microphones and loudspeakers and their relation to musical instruments. I develop four approaches towards microphones and loudspeakers in music. Three of these approaches focus on what I call 'transparent' or 'inaudible' use. The fourth approach, however, focuses on the use of microphone and loudspeakers in an opaque way. They should be 'audible' and function in a way similar to how musical instruments commonly do, and the resulting sound should be formed, coloured and modified by these devices.

Chapter 3 is dedicated to the sound of microphones and loudspeakers themselves: acoustic feedback. In the 'transparent' approaches towards microphones and loudspeakers, feedback sound is avoided under all circumstances, since it suddenly makes the equipment that should stay 'beyond the curtain' audible. By focusing on nineteenth-century inventions that exist as patents, sketches, or just as prototypes, a history of how microphones and loudspeakers 'lost' their own sound is unveiled. Whereas this technology has become completely obsolete for mainstream applications, contemporary artists are exploring and producing sound with uncommon applications of electricity and these kinds of early predecessors.

Not only musical works but also many books have been important for my investigation in microphones and loudspeakers. Several accounts on compositional theories and practices have been written, and especially those on electronic music have been of great import to my research. Two, I would like to mention here in particular, are by Pierre Schaeffer and Trevor Wishart, respectively, who have been describing in their theoretical work in several ways for the categorization of certain compositional aspects. Although their compositional strategies do not necessarily touch my topic, since they focus on shaping the electrical signal, their ideas and types of categorization have been very helpful to me. Pierre Schaeffer develops many different categories for composing 'objets musicales' in his *Traité des objets musicaux – Essai interdisciplines* (Schaeffer 1966, especially 475–560), showing how all kinds of dissimilar sounds can be arranged into one consistent musical entity. Of Trevor Wishart, I have notably looked at his methodology described in chapter 8 'Sound-image as Metaphor: Music and Myth' in *On Sonic Art* (Wishart 1996, 163–176). Wishart describes well why the use of categories is a helpful tool for composing: 'The procedure I shall describe [...] is meant therefore to be merely a heuristic tool, an enabling device to force the imagination to consider possibilities which might not otherwise have occurred to it'. I mention how this kind of imagination might be functioning in composing with microphones and loudspeakers at the end of Chapter 4.

In *Living Electronic Music* (Emmerson 2007), Simon Emmerson discusses several artistic uses of microphones and loudspeakers. Stating that 'The microphone has never been a passive observer' (Emmerson 2007, 118), he describes a short history of microphone development from Alexander Bell's telephone in 1876 onwards. His musical functions of live amplification – balance, blend, projection (and spatialization), perspective, colouration, and resonance-feedback – develop from a microphone being 'an observer (though with character) to an active participant' (Emmerson 2007, 135). His chapter 6 is called 'Diffusion–Projection: The Grain of the Loudspeaker' and its scope is merely on spatialization – the emission of sound through a multiple loudspeakers system – a practice I discuss to some extent in the section on *Space* in Chapter 4. Curtis Roads describes many methods of spatialization of sound in the chapter 'Articulating Space' of his book *Composing Electronic Music: a New Aesthetic* (Roads 2015, 239–282). As he points out, 'The configuration of the loudspeakers (i.e., the number of loudspeakers and their position in space) is another critical factor in spatialization. Only a few configurations are common, such as stereo, quad, 5.1 surround, and octophonic surround' (Roads 2015, 262). For this reason, much experimentation has to be done, as soon as other loudspeaker configurations are used. Another book of great help was *Handmade Electronic Music: The Art of Hardware Hacking* by Nicolas Collins (Collins 2009). This book inspires one in many ways to 'touch' microphones and loudspeakers, instead of having them just placed on stands or hanging from the ceiling. Besides offering many insights into his decades-long experiences with experimental and artistic uses of microphones and loudspeakers, Collins relates these methods to existing artistic works, such as *Rainforest* by David Tudor (which I discuss in Chapter 4) and *Windy Gong* by Ute Wassermann (which I discuss in Chapter 5).

My ideas on musical instruments and the concept of their gestural identity, as explained in Chapter 5, have been highly influenced by Paul Craenen's *Composing under the Skin – The Music-Making Body at the Composer's Desk* (Craenen 2014). Caleb Kelly discusses many ways artists manipulate sound reproduction technology, such as phonographs and CD players, in unusual ways in *Cracked Media: The Sound of Malfunction* (Kelly 2009). Although this book does not cover any microphone and loudspeaker 'malfunctioning', these approaches towards phonographs and CD players could be compared with my *interacting* approach (as described in Chapter 2, and exemplified by many pieces in Chapter 4), since both manipulate devices originally used for reproduction of sound signals, seemingly without adding or changing any sonic characteristics. Kelly's statements could sometimes be rewritten for my microphones and loudspeakers. 'These artists took the passive and transparent microphones and loudspeakers [CvE, in Kelly's text: *the passive and transparent tools for playback*] and manipulated, cracked, and broke them into new forms for creating original compositions, unique performance tools, and new instruments' (Kelly 2009, 40).

I borrowed some of the ideas on musical instruments as formulated by Aden Evens in the book chapter 'Sound and Digits' (Evens 2005). I was especially interested in his concept of opaqueness and the resistance of musical instruments against their players, which stands in opposition to the usual idea of unity between musician and instrument. My notions on nineteenth-century sound reproduction technology have been heavily influenced by Jonathan Sterne's *The Audible Past: Cultural Origins of Sound Reproduction* (Sterne 2003). I take his concept of the tympanic principle and develop the tuning fork principle as a juxtaposition to it in Chapter 3. Many important thoughts for the development of my ideas are expressed in the book *Klang (ohne) Körper – Spuren and Potentiale des Körpers in der elektronischen Musik* (Harenberg and Weissberg 2010b). This book focuses on the loss of the unavoidability of the relationship between playing gesture and the resulting quality of sound by the introduction of electricity. This loss postulates a renewal of our ideas on relationships between musician, musical instrument and electronic sound. Since I teach at the faculty of Music and Media Art in Bern, where this research project was conducted, I experienced the development of the concepts and ideas of *Klang (ohne) Körper* not only through the book itself but by many conversations with my colleagues Michael Harenberg and Daniel Weissberg as well.

Experimental music using electronic means has been omnipresent during the last decades. Electricity did become an increasingly important element in music during the beginning of the twentieth century. It became common during the 1950s and 1960s for composers to visit an electronic studio to compose sounds, or for musicians to play synthesizers. In many books, the role of microphones and loudspeakers, and especially how they, instead of electronic devices such as synthesizers or computers, can 'shape' the sound, is often not discussed at all or just in the margins, since the scope of these books is mostly on the design of the electrical signal itself, the origin of the sound or its aesthetic implications.[1] This book tries to fill this lacuna. Although there is no existing theory on composing with microphones and loudspeakers as musical instruments, many of these books were helpful by giving details on certain microphone or loudspeaker technologies, musical instruments, or compositions.

At the end of this introduction I would like to mention that there is almost no technical information on microphones and loudspeakers included in the book. This is covered very well in existing literature.[2] A thorough knowledge of these technologies can be of great help when experimenting with microphone and loudspeaker technology. I would like to underline, though, that many artists discussed in this book do use the technology in their own way. They are not interested in how microphones and loudspeakers function exactly or how they should be used according to the manual, but rely mostly on their ears to judge their experiments. As the use of acoustic feedback in many of the examples exemplifies, artists are often interested in functions of these devices which have not been taken into consideration by their designers. In reading accounts of artists on their experiments with microphones and loudspeakers, I regularly found remarks by artists wanting to do things differently than the usual ways. As Hugh Davies mentions about setting up the performance equipment of *Mikrophonie I* by Karlheinz Stockhausen: 'The stage electrician and other people helping want to do things "normally," their own way – which is generally exactly the opposite of what we want' (Davies 1968, 11). And that is what this book is about.

Notes

1 Several extensive overviews of how electronic music evolved during the last 100 years have been written; for instance, by Chadabe (1997), Holmes (2008), Manning (2004), Ruschkowski (1998) and Supper (1997). Other books focus on more specified topics of electronic music, with contributions by various authors, for example, Braun (2002), Collins (2010) or Emmerson (1986). Many books explain how creating electronic music is done in a technical way; nowadays, mostly focusing on using computers or other digital media: for example, those by Cook (2002), Farnell (2010), Miranda (2002), Roads (1996) and Roads (2004). Some books that cover topics on certain aspects of composition and sound art with electronic means are by Braun (2002), Young (2002), Warner (2004) and Sterne (2012). Although Brandon LaBelle's *Background Noise: Perspectives on Sound Art* (2006), Paul Hegarty's *Noise/Music: A History* (2007), Salome Voegelin's *Listening to Noise and Silence: Towards A Philosophy Of Sound Ar*t (2010) and Joanna Demers' *Listening Through the Noise: The Aesthetics of Experimental Electronic Music* (2010) place more emphasis on philosophical aspects and are less on compositional methods than mine is, these books have been examples for considering their way of writing and how they focus on understanding electronic music and sound art not so much in only a technical way but as well in their aesthetic points of view.

2 Extensive elaborations on loudspeaker technology may be found in *Historical Perspectives and Technology Overview of Loudspeakers for Sound Reinforcement* (Eargle and Gander 2004), *Loudspeaker and Headphone Handbook* (Borwick 2000), *Loudspeaker Handbook* (Eargle 2003) and *Loudspeakers: For Music Recording and Reproduction* (Newell and Holland 2007). Microphone technology is discussed in detail in *Eargle's The Microphone Book: From Mono to Stereo to Surround – A Guide to Microphone Design and Application* (Rayburn 2012) and a more self-made approach focusing on live performances with musical instruments, especially interesting for artists, is explained in *Getting a Bigger Sound: Pickups and Microphones for Your Musical Instrument* (Hopkin 2002). The book *Electroacoustic Devices: Microphones and Loudspeakers* (Ballou 2009) focuses on both.

1

Beyond the Curtain: The 'True Nature' of Microphones and Loudspeakers

An empty stage: Listening according to the *Konzertreform*

The audience sits quietly in the concert hall. The lights are dimmed. The music starts, but the performers are not visible. The musical performance reaches the audience only through sound, devoid of visual cues. Due to the invisibility of this musical performance – forcing the audience to focus on sound rather than sight – the poignancy of the performance becomes augmented (Wolfrum 1915, 5, 10). The picture at the beginning of this chapter (Figure 1.1) was taken in a concert hall in Heidelberg (Germany) in 1903 and depicts the set-up in the concert hall as used for this kind of invisible musical performance. The orchestra and choir are hidden behind panels and curtains, with the aim of eliminating

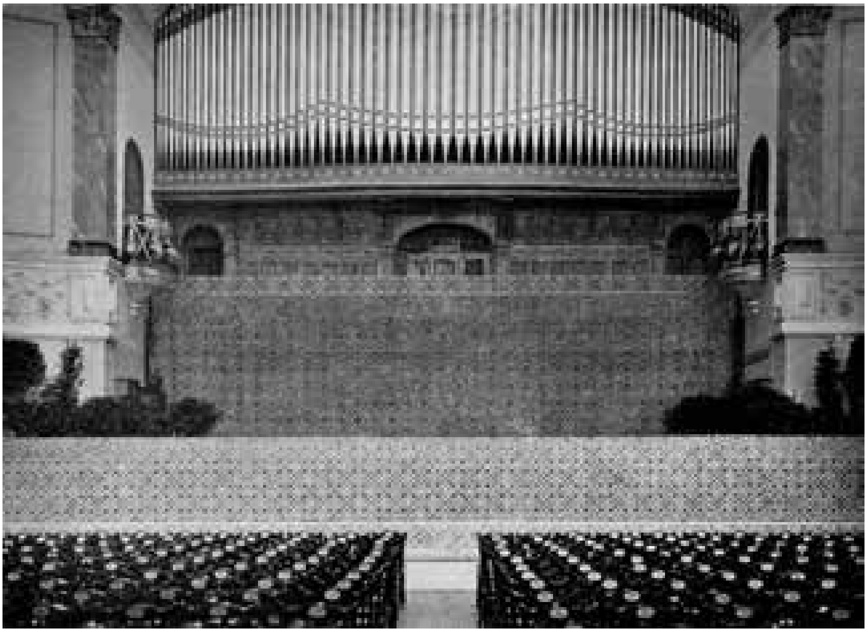

Figure 1.1 *Konzertreform*: to hide the choir and the orchestra panels were installed in the concert hall 'Stadthalle' in 1903 Heidelberg, Germany (Schuster 1903/04).

anything that might distract the eye and the ear of the audience (von Seydlitz 1903, 97). All distracting movements of the performers, for example the ‘prima donna coquetry by certain conductors’ (Wolfrum 1915, 5), take place behind a curtain, and only that part of the audience which needed to ‘learn’ from the performance, such as music students, was permitted to sit on the other side of this curtain, able to view the conductor and musicians.

These conceptualizations of a concert practice which would focus as much as possible on only the audible elements of music were formulated and put into practice by several musicians at the beginning of the twentieth century, mainly in Germany, in the context of what contemporary theoreticians termed *Konzertreform*. Whereas the core idea of this movement – presenting music with the performers hidden behind curtains – did not persist, many of the postulations of this *Konzertreform* formed part of a drastically changing concert practice, from the end of the nineteenth through the beginning of the twentieth century. By the end of the nineteenth century, the audience was expected to be as silent as possible during the musical performance and not to talk out loud anymore, hum with the music or beat the rhythm with hands, head, or feet (Johnson 1996, 232–233). Additionally, applause during symphonies was abandoned and only allowed to happen at the end of a piece of music, instead of after each movement or even during the music itself (Ross 2010). Apparently, all of this audience behaviour was previously considered normal, or at least possible, during concerts, otherwise the formulation of such rules would have been unnecessary. Many other common features of classical music concerts nowadays were introduced in relation to the *Konzertreform*. For example, a large foyer between the entrance and the concert hall, creating a division between the social activities of the audience and the activity of listening, was deemed necessary (Marsop 1903, 433). In this way, the social interaction which used to take place within the concert hall during the performance could now take place outside. A sound signalling the start of the performance was initiated, giving the audience the chance to become completely silent (von Seydlitz 1903, 100). Concerts should take place in darkened concert halls, so that audience members would not be visually distracted. The aim of all these sanctions was to ‘give the sense of hearing full priority for the audience member, through putting to rest the eye, his biggest enemy’[1] (Holzamer-Heppenheim 1902, 1293).

Most of the aforementioned claims have become enduring conventions for classical music concerts. The extreme practice of hiding the musicians behind curtains during the concert as described at the beginning of this chapter should be regarded as a by-product of a larger aim or programme to achieve more focus on the purely sonic aspect of the music. Many of the proclaimers of the *Konzertreform* were inspired by the sonic phenomenon of the famous invisible orchestra in Richard Wagner’s theatre in Bayreuth (Marsop 1903, 428–429). The curtains hiding the musicians had not only a visual aspect but served an acoustical purpose as well. Making use of the good acoustic conditions in the Bayreuth theatre (nowadays called Richard Wagner Festspielhaus) as well as the indirect sound of the orchestra, due to the orchestra pit being recessed, the sound was perceived as ‘cleaned’ by this so-called ‘sound-wall’ (von Seydlitz 1903, 99). Sound waves could not reach the audience directly because of the curtain, which transformed the sound of the orchestra into something mellower. As a result, the hidden musical instruments could be located easily neither by the ears nor by the eyes of the audience. The aim was to avoid focusing in a specific direction, and thus to achieve a listening situation in which the audience would be completely overwhelmed by sound alone, absent of any material source recognizable as the cause of this sound. Considering that up to that time church organists were one of the few instrumentalists hidden from the audience, placed in the back of the church on a balcony, it might come as no surprise that this concert practice – as it was developed during the end of the nineteenth and the beginning of the twentieth century – has been called a religious ritual, eliciting remarks that the listening attitude might be compared with silent praying (Tröndle 2009, 47). The only important feature of a music performance was the contact between the listener and the sound of the music; all other elements were considered to be a distraction. The possibility of music performances existing in the form of sound alone arose, and for many audience members, such as the advocates of the *Konzertreform*, this situation was preferable to that of a conventional concert.

A concert at home: The invention of sound reproduction technologies

Whereas the ideas of the *Konzertreform* did not endure in actual practice, listening to music without any distraction of, for example, musicians' movements or audience members' noises became possible in another way. In listening to music on a record or on radio, listening conditions similar to the ones set into practice by the *Konzertreform* became mainstream. In fact, the ideas developed around the phenomenon of the classical music concert, resulting in the sound of a musical performance being the most or even the only important element of music, were essential to the development of a music performance culture mediated through radios, gramophones and CD players at home. These devices are all commonly called sound reproduction technologies due to their primary function. This technology was developed in a cultural context calling for the emancipation of sound, which was understood as sound being recognized as the only element necessary for a complete perception of music, instead of the integral musical performance, all visual aspects included. The idea that nothing fundamental was missing when visual aspects of musical performance are excluded was therefore a necessary context for the successful rise of music recordings as replete musical experience during the last century. Listening to a musical performance on the radio can therefore feasibly be considered as a successor of listening to a concert in a concert hall where the performers are hidden (Schwab 1971, 186).

It is often averred that inventions like the phonograph or the radio force the audience to listen to music without viewing its source and effected 'the physical separation of listening from performing' (Chanan 1995, 7). I would argue, however, that the ideals of the *Konzertreform* clearly reveal that this new mode of perceiving music was not necessarily preceded by the invention of new technology, but can be seen as an aesthetic development which took place during the nineteenth century, concurrent with the invention of sound reproduction technologies such as telephones, phonographs and radios. Although these kinds of devices did not instigate a new way of perceiving music, they did make it much easier to listen only to the sound of music instead of perceiving the whole performance, including its visual elements. A singular sound can only exist at a specific time and at a specific place, since it is formed by waves of pressure that are by definition in constant motion. Before the invention of sound reproduction technology, music never took place without the presence of musicians and their musical instruments, or – in the case of music automata – at the very least the presence of the musical instruments. Listening to music was directly connected to this presence of musical instruments. The *Konzertreform* attempted to disconnect the audience as much as possible from this presence by hiding the instruments behind a curtain, but it was through sound reproduction technology that, for the first time, they no longer needed to be present in the same space or at the same time as the listener. What all sound reproduction devices have in common is that they release sound from its direct connection to a certain time and space. This is done in two ways: either by storing sound (taking it out of its time) and by transporting or amplifying sound (taking sound out of its place). The sound waves – air pressure waves[2] perceived by the human reception system as sound – are transformed into a form of energy which dissipates less than air pressure waves. As I make clear in the next paragraphs, microphones and loudspeakers are crucial to the transformation of sound waves, since they are transducers of air pressure waves to this more enduring form of energy: an electrical signal.

Storage of air pressure waves

In order to store air pressure waves, their time-related form consisting of pressure differences needs to be translated into another, more sustainable material, such as wax, vinyl, magnetic tape or any form of contemporary digital storage, for example. The sound is now coded not through pressure differences in air but through differences in the depth or deviation of a groove, differences of magnetic power or binary numbers. This information is transformed back to air pressure waves either by using a mechanical, such as early phonograph needles, or an electric conversion system, used by nearly all sound reproduction devices nowadays, which brings into vibration a diaphragm.

Jonathan Sterne* did extensive research on sound reproduction technologies and their cultural origins. In his book *The Audible Past* he proposes the idea of the tympanic mechanism, informed by the human eardrum, as a mechanism for transducing vibrations (see Chapter 3 for a more in-depth discussion of the tympanic function). This tympanic mechanism is (re)produced in the sound reproduction technology found in microphones and loudspeakers, their diaphragms being comparable with the membrane of the ear.[3] As Sterne describes clearly: ‘every apparatus of sound reproduction has a tympanic function at precisely the point where it turns sound

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* The asterisk behind names indicates that there is a short representation of the person in the appendix of this text.

into something else – usually electric current – and when it turns something else into sound. Microphones and speakers are transducers; they turn sound into other things, and they turn other things into sound' (Sterne 2003, 34). Devices used for the transformation of air pressure waves to something else and vice versa is therefore how I define microphones and loudspeakers. Although there have been many new inventions within sound reproduction technology since the end of the nineteenth century, such as electric amplification, digital recording and processing, 'it is still impossible to think of a configuration of technologies that makes sense as sound reproduction without either microphones or speakers' (Sterne 2003, 34–35). Whereas there are many different technologies to store sound, like gramophone records, cassette tapes, CDs and MP3s, the connection between air pressure waves and the electrical signal is nearly always performed by microphones and loudspeakers.[4]

Transportation of air pressure waves

What distinguishes the tympanic principle from other ways of producing sound is that – ideally – all kinds of sounds can be produced by the same membrane, hence also the term sound *re*production technology. The idea of using a membrane for converting sound waves into 'something else' can, for example, also be demonstrated in the so-called tin can telephones. Two tin cans, paper cups, or similar objects are attached to each end of a wire. Speaking softly in one of the cans causes the bottom of the can to vibrate. This bottom functions as a membrane able to vibrate in response to various air pressure waves. These vibrations are transported along the wire to the bottom of the other tin can. A person at the other side of the wire will therefore be able to hear the sound, as transported from one tin can bottom to the other by the wire. This simple 'telephone' reveals how crucial the tympanic mechanism as described by Sterne is for sound reproduction technology. To reproduce a sound, there is no longer need for a mechanical reconstruction of the objects that produced that sound, as for example in the case of musical automata. Therefore, instead of creating a different sound-producing device for every sound, the membrane – more specifically called diaphragm – was incorporated as a general solution for the conversion of sound into mechanical vibrations or an electrical signal and back: a metaphorical tin can is used at both ends of the wire, functioning once as microphone and once as loudspeaker. The tin can telephone is nowadays replaced by a telephone which uses electricity to transport the transduced sound waves. An electrical signal is transported by a wire, with a small microphone and loudspeaker at either end to make transductions between air pressure waves and electricity.

Amplification of air pressure waves

Air pressure waves lose energy when they move through the air. Already in ancient history solutions were sought for this problem. Sound is normally dispersed in all directions. By focusing sound waves with a horn, the sound waves are all forced to move into one direction. As a result, audiences will hear the sound louder. Horns are therefore used for sound amplification (although physically speaking they are only focusing and not amplifying sound waves). In ancient Greek and Roman theatre, masks were introduced which not only helped the spectators to distinguish the characters but also served as amplifiers for the actor's voice. The opened mouth of the mask was shaped in the form of a horn (Floch 1943, 53). The horn was used to amplify the human voice, so more spectators could clearly hear what the actor was saying. This horn could therefore be seen as fulfilling the same function as microphones, amplifiers and loudspeakers nowadays, to amplify the actors' and/or singers' voices on stage.

Till the end of the nineteenth century, 'amplification' (in fact focusing) of sound waves was mostly achieved using horns, often much bigger than those integrated into the Greek masks. A late example is the large megaphone (1878) developed by Thomas Edison* (Figure 1.2). This megaphone is nothing more than an enormous enlargement of the human ears and mouth, similar to the enlargement of the mouth by the Greek mask. Two large metal or wooden horns around 180 centimetres in length were used as ear enlargements, and a third horn was placed in front of the mouth. In this way Edison was able to communicate over distances of more than three kilometres (Dyer 2004, 89–90). Edison claimed that he was even able to hear 'a cow biting off and chewing grass' (Baldwin 2001, 91). What these horns evidence is that for a significant amplification of sound, whether sending or receiving and without the use of electricity, an enormous object is needed. After the introduction of electricity

Figure 1.2 Thomas Edison's megaphone (Anonymous 1878).

into the process of sound amplification, the amplifier horn became obsolete. Since Edison invented his megaphone at the same time as the telephone (invented in 1876), his megaphone was, in the end, not used for communication over long distances. This was done much more effectively with the new telephone technology. Amplification of air pressure waves with the help of electricity became an important function of sound reproduction devices. During concerts, the amplitude of sound waves produced by singers and instrumentalists could now be increased by making use of electricity. Due to the use of the Audion, an electronic amplifying tube invented by Lee De Forest* in 1906, it became possible to enlarge the electrical current produced by the output of microphones. The loudspeaker diaphragms could therefore produce much larger air pressure waves than those which the diaphragms of the microphones had originally picked up. This form of electronic amplification became mainstream in the 1920s (Morton 2004, 65).

Between air and electricity

The aims of sound reproduction technologies are much older than devices like phonographs, radios and telephones. It is much more accurate to see the development of sound reproduction technologies, and thus the development of microphones and loudspeakers also as a long process, during which ideas concerning sound, musical aesthetics as well as technology mutually influenced each other. As Sterne makes clear, these sound reproduction technologies using microphones and loudspeakers should be understood as 'embodiments and intensifications of tendencies that were already existent elsewhere in the culture' (Sterne 2003, 34). All basic components of the phonograph (stylus, diaphragm, horn) had been already in use for centuries, and there is technically no reason why this invention has not been fulfilled earlier. But an invention is not only technique but also aesthetics and culture (Chanan 1995, 2).

The use of electricity turned out to be the most efficient medium to counteract the dissipation of sound into the air. Sound could be reinforced and transported without the use of electricity also, but electricity made all these processes much more effective. Many of the disadvantages of purely mechanical sound reproduction technologies were improved by the use of electricity. It is therefore not surprising that it was only after the introduction of electrical recording and amplification in the mid-1920s that these new sound reproducing devices became truly valuable for music-listening culture, as has been analysed by many authors. Michael Chanan, for example, describes the introduction of electricity in his book *Repeated Takes* as follows: 'The audible limitations of the early phonograph were musically restrictive, and remained so, despite a constant stream of improvements, until the introduction of electrical recording in the mid 1920s, when the disc was joined to amplification and the loudspeaker' (Chanan 1995, 37). In *The Audible Past*, Jonathan Sterne mentions how electric amplification was clearly preferred by the audience: 'By all accounts, audiences preferred the sound of radio – which used vacuum tubes and electricity to receive, transmit and reproduce sound across space' (Sterne 2003, 276), and Mark Katz underlines the improved sound quality, as concerns the reproduction of sounds, that was introduced by the use of electricity: 'The development of electrical recording made it possible to reproduce a much larger spectrum of sound' (Katz 2004, 83). Horns such as those used in early phonographs add much more of their own acoustic characteristics to the sound waves than a loudspeaker diaphragm does. Due to the use of electric valves, horns were no longer needed for the recording or amplification of sound, so the resulting electric recording had less sound distortion. The advantage of converting sound waves into an electrical signal was already described in 1877: 'The original sound dies like any other sound, but its photograph, as it were, has been copied in a more subtile medium than air, and so it lives and moves and is born again' (Lovewell 1877, 28).

Microphones and loudspeakers are located in between air pressure waves and something else. This something else is usually an electrical signal, so microphones and loudspeakers could be regarded as being *between air and electricity*. These devices are in touch with the physical world of pressure waves that dissipate in the air as well as with an endless electrical signal that need never end as long as it is connected to an energy source. This in-between position between the acoustical world consisting of physical material and laws (*air*) and the electric world which has the possibility to become entirely virtual (*electricity*) is occupied by microphones and loudspeakers, which is unique compared to all other sound-producing devices.

A standard, almost perfect amplifier and loudspeaker

Reproducing music

Direct comparisons were often made between listening to a loudspeaker at home and music listening in the concert hall: 'The listener who hears a symphony or string quartet through his loud-speaker loses little that is essential. His impression of the work is nearly, if not quite, as vivid and complete as if he were seated in the concert hall' (Damrosch 1935, 93). The microphone and loudspeaker were able to record and reproduce a musical performance because by the time that sound reproduction technology became mainstream at the beginning of the twentieth century, it had also become common to think of sound as being the only desirable component of a musical performance. If viewing the gestures of a singer had been regarded as an essential aspect of a musical performance, it would have been much more difficult to convince audiences that listening to a record at home is comparable to attending a musical performance in a concert hall. Recognizing the acoustic characteristics of a performance – such as the melody and chords – was enough to have an impression of the work nearly as good as in the concert hall, already in 1935, in a time where recording quality was miserable in comparison to what we are used to nowadays.

To become ideal reproducers of musical performances, sound reproduction technologies, and especially their input and output in the form of microphones and loudspeakers, should reproduce sound without themselves being audible. 'The ideal loud speaker should be entirely free of resonance and should reproduce all audible frequencies equally without adventitious aids' (Rivers-Moore 1929, 405). Listening to music through loudspeakers at home in the living room should be comparable to attending a concert in the style of the *Konzertreform*: the impression should be that the musicians are present in the same space, but hidden behind a curtain.

Composing music

Alongside using microphones and loudspeakers to reproduce music performances or to amplify musical instruments, there were speculations about new opportunities for composers, now that they could use microphones and loudspeakers for their work. Otto Kinkeldey* discusses future opportunities of the 'sound film' and the 'loudspeaker' in 1937:

> If the musician could be enabled to manipulate his sound effects as the painter handles his pigments, if he could mix his tones and overtones, his tone-colors and tone-shadings in infinite variety without the aid of the artificial sound producers which we now call musical instruments, and if finally he could fix the resulting complicated sound curve upon a lasting medium like the sound film, capable of being acoustically reproduced at will with the aid of electric apparatus, he will have reached the autonomy and independence of the painter. (Kinkeldey 1937, 4)

What Kinkeldey describes here is exactly what many composers engaged in after the 1950s, when composing electronic music for magnetic tape. Part of Chapter 2 is devoted to this new approach to composing, which I term the 'generating approach'. Composers may produce music without the help of any musical instruments and are indeed able to define the spectrum of the sounds they create. To accomplish these tasks the composer 'will possess a standard, almost perfect amplifier and loud-speaker, and will have the inestimable advantage of being able to hear his work played to him, with all its tone colours' (Stevenson 1936, 798). According to this article, the listener will have a similar standard amplifier and loudspeaker, so that exactly the same sound can be heard by the listener as by the composer. The next consequence is 'to abolish the performer', since the process of performance and composing has now become one. The performer does not have to be hidden behind a curtain anymore, but is not needed at all anymore. This perfect amplifier and loud-speaker could bring to sound immediately the ideas created in the head of the composer. Whereas the idea of both composer and audience using exactly the same equipment was never fulfilled, much music produced nowadays is only meant for listening to through loudspeakers or headphones in a private atmosphere. The recording is not a copy anymore of the live performance, but is a genuine musical performance in itself. By the time the Beatles had become a studio band, and participated in the producing work for albums such as *Revolver* (1966) and *Sgt. Pepper's Lonely Hearts Club Band* (1967), it had become indisputable that music could be composed for recording instead of for performance.

Apart from listening to records at home, loudspeakers were also introduced in the concert hall. For listening to music for which only loudspeakers are used as sound producers during a concert, without any musicians on stage, Pierre Schaeffer* proposed in the 1960s the idea of acousmatic listening.[5] Schaeffer refers to the teaching praxis of the Greek philosopher Pythagoras as an example (Schaeffer 1966, 91). According to the myth, Pythagoras would seat himself behind a curtain, and his students would listen to him in complete silence, without seeing anything, so his visual presence would not distract the students. Schaeffer compares this kind of listening, to sound with the source hidden behind a curtain, with listening to sounds through a loudspeaker. 'In addition, the difference between the experience offered by Pythagoras and the one we have with radio and recorded sound, whether listening directly (through a curtain) or listening indirectly (through a loudspeaker) becomes, in the end, negligible' (Schaeffer 1966, 93).[6] The Pythagorean listening situation is evidently very similar to the ideas of the *Konzertreform* mentioned at the beginning of this chapter, both using curtains to hide the source of the sound. Schaeffer, who was probably not acquainted with this German idea of music performance, postulates similar ideas towards listening to music as those proposed by the advocates of the *Konzertreform*: '[the acousmatic situation, CvE] symbolically forbids us every connection with the visible, touchable and measurable' (Schaeffer 1966, 93).[7] The *Konzertreform* could thus not only be seen as a predecessor of the listening conditions created through recorded music and radio broadcasting conventions but also with the listening attitude adapted during a so-called loudspeaker concert. During these concerts, there are no longer any musicians present to be hidden behind curtains, since all sound comes from loudspeakers.

Microphones and loudspeakers: The musical instruments of our age?

Most music is produced nowadays with the help of microphones and loudspeakers, and most of the music people listen to is heard through loudspeakers (Worby 2004). They are used to produce and reproduce music recordings as well as for diffusing sound during concerts: 'listening to music over loudspeakers has become a virtually inescapable condition of life' (Moore 1980, 225). Music of every scale and genre – such as a soloist, a rock band or a symphony orchestra – is said to be recordable (Chanan 1995, 70). The use of microphones and loudspeakers in music has made music more intimate, since a single person can listen to a recording at home, or, even more privately, on headphones, which are of course nothing but small loudspeakers. And the opposite became possible as well: microphones and loudspeakers increased the possible audience size for a single performance, with the result that tens of thousands of audience members can enjoy the same concert with the help of amplification. Under these circumstances, one could say that nearly all music has become microphone and loudspeaker music. Listening to music which uses no electric means has become the exception, taking place mostly during classical music concerts. And even in this field, electricity has been seen to have advantages as well: the lute player Rolf Lislevand even sees microphone technology used during CD recordings as a possibility to recreate the intimacy of seventeenth-century performances: 'The intimate sound of the clavichord, once whispered into a young noblewoman's ear, now flies into a nearby microphone' (Lislevand 2006, 18).

It might be no surprise that, due to the omnipresence of microphones and loudspeakers in music, it might be possible that 'the true instrument of our age is not the lute or guitar or piano or drum or organ or even the electronic synthesizer – it is the *loudspeaker*' (Moore 1980, 214). What would this imply for music and for composing, if the loudspeaker and therefore its partner the microphone also are the musical instruments of our age? If almost all music is heard with the help of microphones and loudspeakers, what kind of instrumental identity is connected to these devices? And is it not indispensable that a musical instrument be recognizable through a typical sound of its own? How do composers and sound artists work with these instruments? Due to the omnipresence of microphones and loudspeakers in music, their applications are innumerable and cover a very broad spectrum of possibilities for music, performance and sound.

The 'true nature' of microphones and loudspeakers

Two works with microphones and loudspeakers by Dick Raaijmakers* could be seen as diametrically opposed to the ideas of acousmatic music and the *Konzertreform*. Raaijmakers thinks of the transformation of sound into an electrical signal as a reduction of three-dimensional, spatial music to a narrow, one-dimensional, electric current. As well '[…] due to the presence of microphones in our society, there has come to exist a surplus of passively reproduced sound generated and a shortage of autonomous composed music' (Raaijmakers 2007, 318).[8] Raaijmakers develops several pieces in which he is looking for this 'distinctive voice' (Raaijmakers 2007, 318) of the microphone itself (*Intona* 1991) as well as the 'true nature' (Raaijmakers 1971, 14) of the loudspeaker (*Drie Ideofonen* 1969–1973). Comparing this undertaking of Raaijmakers with the aims of sound reproduction technology, it becomes clear that they are diametrically opposed: for sound reproduction microphones and loudspeakers should be as transparent as possible while converting air pressure waves to an electrical signal and back in reproducing a recording. There is thus no possibility for a distinctive voice or revealing their true nature.

To understand what the distinctive voice or true nature of microphones and loudspeakers could be, I would like to call to attention the term for these devices as employed by Roelof Vermeulen*. He designates microphones and loudspeakers as acoustical motors, since they are, similar to the function of other motors, converting mechanical energy (the diaphragm movements caused by for example air pressure waves) into electrical energy and vice versa (Vermeulen 1937, 378). To call microphones and loudspeakers acoustical motors turns them into active devices that produce movement – in this case vibrations perceived as sound – instead of passive reproduction devices. Evidently, in technical terms, nothing changes in the actual functioning of these devices. However, considering Raaijmakers's approach towards them, it seems to be more appropriate to see them as motors for acoustical purposes.

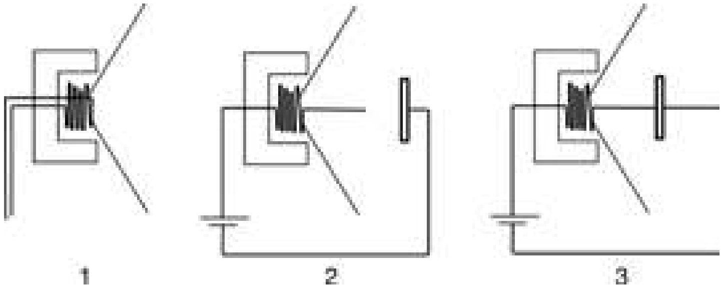
Raaijmakers was at one time working at Vermeulen's department, so it is possible that he was acquainted with his acoustical motor idea.

In approaching loudspeakers as acoustical motors, it becomes clear that these devices consist of material that must vibrate in order to realize the transformation of electrical energy to mechanical energy. Since every vibrating material will vibrate more easily, and therefore with greater amplitude, at certain frequencies – so-called resonant frequencies – and will vibrate less easily at other frequencies, the characteristics of the vibrating material itself will always have an influence on the final sound result. Already the many different types of microphones and loudspeakers reveal the fact that there is not one type of ideal device that can 'inaudibly' reproduce sound, and that all these devices might sound different according to their intended purpose. It is for this reason that many artists have become interested in using microphones and loudspeakers in their works as sound producers and sound shapers. Such artists use them, indeed, as a kind of acoustical motor playing an active part in the musical performance.

An exploration of these acoustical motors was made by Raaijmakers in *Drie Ideofonen*.[9] In line with what was mentioned before, the loudspeakers in these three installations should reveal their true nature through 'talking' to themselves in the absence of any input. As Raaijmakers says:

> For once the gaping loudspeaker should turn inwards and listen to itself: in short, the loudspeaker should be made to hear the sound of its own loud voice, the Loud Speaker should be turned into a Soft Hearer, Hearer and Speaker should be joined together and, for the first time in the history of acoustic communication, the loudspeaker has found itself [...]. (Raaijmakers 1971, n.p.)

Raaijmakers wants the loudspeaker to *shape* the electrical signal to be transformed into air pressure waves, instead of simply transducing an already-existing electrical signal. The loudspeaker has to become both a microphone, called Soft Hearer in the citation above by Raaijmakers, and a loudspeaker at the same time. To achieve this, the output energy of the loudspeaker is controlling its input energy. The output energy is the vibration of the diaphragm, which controls the input energy, in the form of an electrical current. Scheme 1.1 depicts this general principle as used in the *Drie Ideophonen*. Commonly, in a loudspeaker using an electrical signal to produce sound, two different types of magnets are used to bring a diaphragm into motion. One of these magnets is a permanent magnet, the other an electromagnet, consisting of a coil of wire and usually called voice coil. By sending an electrical current through this voice coil, it becomes magnetized. Depending on the direction of the current, the electromagnet will be attracted or rejected by the permanent magnet. A diaphragm, often cone-shaped, is attached to this voice coil and therefore moves along with the coil. This diaphragm brings air into motion and in this way causes air pressure waves. As soon as these air pressure waves are produced with the right speed and amplitude human beings perceive them as sound. The stronger the electrical signal received by the loudspeaker, the bigger the diaphragm moves forwards or backwards, the louder the sound heard.



Scheme 1.1 *
(1) A simplified depiction of a moving coil loudspeaker.
(2) Dick Raaijmakers connects the poles of the loudspeaker to a battery.
(3) The metal plate is pushed away by an extension attached to the moving coil and breaks the connection to the battery.

For *Drie Ideofonen* the electrical signal is not alternating but has a steady value. This causes the loudspeaker diaphragm to move to its frontal position, as soon as it is connected to this electrical signal. This connection is made with the help of a small metal plate. As soon as the diaphragm moves backward, it pushes the plate away, and the connection with the electrical signal is lost again, causing the voice coil to loose its magnetized field and thus to move backwards. The small plate falls back as well, closes the electric circuit again, bringing back the current in the magnet and as a result the diaphragm moves forwards. The connection between the loudspeaker and the electrical signal is controlled by the diaphragm movement itself. But is this still a loudspeaker? In fact the system has just two states: connected or disconnected. The method of sound production might therefore be regarded as a kind of percussive musical automaton. The commonly held identity of the loudspeaker – as output of sound reproduction technology – is no longer valid. The loudspeaker has indeed become a sound producer instead of a reproducer.

In his piece *Intona* Raaijmakers looks for the distinctive voice of microphones, by drilling, sawing, cooking, burning or dissolving them. The performer is, as Raaijmakers emphasizes, playing the microphone as a musician. Many microphones are built quite similar to the loudspeaker described above, but functioning the other way around. The diaphragm is not producing air pressure waves, but vibrates according to air pressure waves in its surroundings. With the help of an electromagnet and a permanent magnet these diaphragm movements are then transformed into an electric current. To produce sounds solely made by the diaphragm itself, the diaphragm is brought into vibration, not by air pressure waves as is usually the case, but by, for example, a drill, a saw and boiling water. In this manner, the microphone should reveal its own voice. The function of the device has not only been changed from reproducing to producing sound, but the

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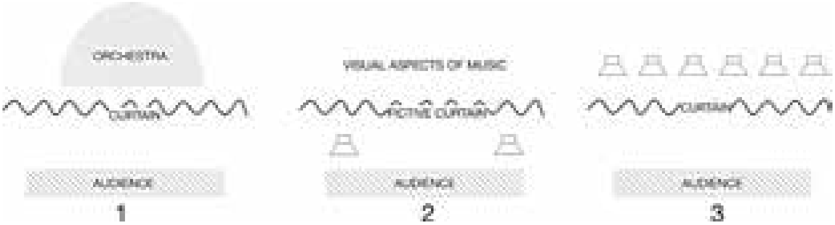
* All schemes in this book are original work by Cathy van Eck.

microphones themselves are even destroyed by the attempt to make their diaphragms, as such, audible.

As the two examples of Raaijmakers' work reveal, while trying to discover the distinctive voice and true nature of microphones and loudspeakers, these devices, as a direct result of this search, cease to exist. Underlining this idea is the burning of the loudspeakers through which the microphones were amplified at the end of *Intona*, which action, according to Raaijmakers, causes the material qualities of microphones and loudspeakers to be lost. If microphones and loudspeakers were truly to be able to reproduce sound, they should possess no material characteristics, something which is of course impossible. Kees Tazelaar*, who collaborated on several of Raaijmakers' music theatre pieces, says, '[t, CvE]his ritual burning of loudspeakers seems to have stood as a symbol for a utopian idea according to which Raaijmakers demands the invention of technology to enable the holographic projection of sound through space, without any help from loudspeakers' (Tazelaar 2011, 28). This idea of holographic sound production in space without loudspeakers is described by Raaijmakers himself in his book *Cahier M* (Raaijmakers 2000, 102–103). The closest realization of this holographic projection of sound can be found nowadays in Wave Field Synthesis (WFS). In this practice, many loudspeakers are used to project virtual sound sources into the performance space (Boone 2001, 4). The loudspeakers themselves – in general hundreds or even more than a thousand are used – should not be audible at all in this kind of application. The sound seems to be diffused from a source in space only recognizable by the ear, without any visual cue whatsoever, not even a black loudspeaker that might serve as visual reference for the sound that is produced. This act of producing such an illusion of a virtual sound source has its origins in stereophonic sound reproduction, as developed during the 1930s and 1940s: 'an illusion of a single sound pulse coming from a virtual sound source located somewhere in the space between the outer loudspeakers' (Snow 1955, 46). The main aim of stereophonic sound is not to reproduce sound with two channels, as is often thought, due to familiarity with the common living room stereo set with two loudspeakers. Stereophonic sound is a technology in which the illusion of several sound sources is created in between the loudspeakers, of which there can be more than two, but two are needed at least to create these so-called phantom sound sources.[10] The sound should be projected in space as if coming from a 'screen' (Snow 1955, 45). During experiments in the 1930s to determine how many loudspeakers needed to be used in order to create these virtual sources in stereophonic sound, the loudspeakers were hidden by a curtain (Steinberg and Snow 1934, 12). By hiding the loudspeakers behind a curtain, it should have become impossible for the listener to hear how many loudspeakers were on stage and what their placement was (Scheme 1.2).

A curtain is used in the *Konzertreform* to hide the musicians. Schaeffer evokes a curtain hiding visual aspects of sound sources as an analogy for listening to sounds through a loudspeaker. This third curtain employed in stereophonic sound reproduction is now used to hide even the loudspeakers themselves. Listening to music through loudspeakers should approach pure sound listening, without any visual cues. The sound source should become an illusion. The use of a WFS system could therefore be seen as an advanced version of the *Konzertreform*. WFS technology places



Scheme 1.2
Three different curtains, all hiding the source of the sound.
(1)The curtain of the *Konzertreform* hides the musicians.
(2)The curtain of Pierre Schaeffer hides all visual aspects of music.
(3)The curtain in stereophonic sound reproduction hides the loudspeakers.

virtual sound sources inside as well as outside the performance space, since there are no physical constraints. Although the loudspeakers are no longer hidden by a curtain in this type of set up, it is often advised to listen to the system with the eyes closed, a solution that in fact is not very different from using a curtain to hide the sound sources.

To remain in the same analogy, Raaijmakers opens the curtain, which in stereophony hides the loudspeakers. By opening this curtain he searches for their true nature. That this might not be so easy is signified by the transformation which microphones and loudspeakers undergo in both performances: the devices are modified to such an extent that it becomes difficult to say whether they might still be regarded as microphones and loudspeakers. The loudspeakers in *Drie Ideofonen* are talking to themselves and all microphones and loudspeakers used in *Intona* are completely destroyed by the end. But is this indeed the only way to find their 'distinctive voice', or could the reproduction of sound perhaps also be a part of their distinctive voice? All sound radiated by loudspeakers is produced by the loudspeaker diaphragm; viewed this way, one might assert that they are not able to produce anything else than their own sound. The same is true for the microphone: the electrical signal it produces is always derived from the diaphragm movements themselves. It is in between these two extreme positions that my research has been situated: sound produced out of nowhere with inaudible microphones and loudspeakers, on one hand, and making microphones and loudspeakers audible by playing them as a musician, on the other.

Notes

1 My translation of 'dem Gehör den Vollbesitz über mich zu verschaffen, dadurch, dass ich seinen grössten Gegner, das Auge, ruhen lasse' (Holzamer-Heppenheim 1902, 1293).

2 In fact, certain microphones like piezo-ceramic ones can measure pressure differences in material other than air. Sound can be propagated through all gases, as well as liquids and solid materials; however, since human beings listen to sound, especially music, primarily through air conduction, I will not consider these other materials here.

3 Although most microphones and loudspeakers utilize a diaphragm for picking up or emitting air pressure waves, some exceptions function without a diaphragm (Sennheiser 1999, 1052). Since the use of an element other than a diaphragm for picking up or radiating sound waves is very rare, I will not discuss these other possibilities in more detail here. The function of these other elements is still the same as the diaphragm in every microphone or loudspeaker: to transduce (air) pressure waves into another form of energy or vice versa.

4 As exceptions, there have been other ways of (re)producing sounds, for example using flames (see *Der sprechende Flammenbogen und die Telephonie ohne Draht vermittelst Lichtstrahlen – Zwei Instrumentarien zur Demonstration* [Ernecke 1897] and *Chemische Harmonika – Über die Entstehung eines Instruments zwischen Phlogiston und Pyrophonie* [Gethmann 2010]) or plasma speakers such as Tesla coils (see *Tesla Coil* [Trinkaus 1989]).

5 A very thorough investigation in the history and cultural roots of acousmatic sound can be found in Kane (2014).

6 My translation of 'Par ailleurs, entre l'expérience de Pythagore et celle que nous font faire la radio et l'enregistrement, les différences séparant l'écoute directe (à travers une tenture) et l'écoute indirecte (par haut-parleur) deviennent, à la limite, négligeables' (Schaeffer 1966, 93).

7 My translation of '[la situation acousmatique, CvE] nous interdit symboliquement tout rapport avec ce qui est visible, touchable, mesurable' (Schaeffer 1966, 93).

8 My translation of 'is er door de aanwezigheid van microfoons in onze samenleving een teveel aan passief gereproduceerd geluid ontstaan en een tekort aan autonome met elektronische middelen vervaardigde en gecomponeerde muziek' (Raaijmakers 2007, 318).

9 Dutch for *Three Ideophones*.

10 A multifaceted history of stereo – not limited to the sound system, but also looking at social and economic aspects – can be found in *Living Stereo: Histories and Cultures of Multichannel Sound* (Théberge, Devine and Everrett 2015).

2

Reproducing – Supporting – Generating – Interacting: Four Approaches towards Microphones and Loudspeakers

Made for music: Concepts on musical instruments

Music, in general, seems to be made with the help of musical instruments. The assumption that music is made with instruments seems to be so largely accepted that there is little doubt about the crucial relationship between music and instruments or ambiguity about what musical instruments might be at all.[1] As the philosopher Philip Alperson says, ‘the idea of the musical instrument seems central to our understanding of the musical art’ (Alperson 2008, 37). However, defining what those objects called musical instruments actually are can prove problematic, as the article on the *Classification of Instruments* in *The New Grove Dictionary of Music and Musicians* puts into words: ‘“Musical instrument” is a self-explanatory term for an observer in his own society; it is less easy to apply on a worldwide scale because the notion of music itself in such a wide context escapes definition’ (Wachsmann et al. 2013). Instruments are so closely connected to the performance of music that they seem to be inseparable from music itself. If an artist wants to make music, he or she will do this with the help of musical instruments.[2] The instrument seems to be not only a transportation vehicle for music but also a premise for its existence. The composer Atau Tanaka describes this relationship well: ‘If concert performance is the medium of communication then the instrument becomes the conduit between performer and listener. The listener’s perception of the music is contingent on the instrument’s efficiency at transmitting the performer’s musical expression, and the performer’s ability to channel his creativity through his instrument’ (Tanaka 2000, 389). But what happens when microphones and loudspeakers are essential to the music-making process? Could these devices be considered musical instruments as well? Microphones and loudspeakers are used for transformations between air pressure waves and something else, commonly electricity. But what are musical instruments? Which objects should be considered musical instruments, and which should not? By investigating the instrumental characteristics of microphones and loudspeakers not only more knowledge on composing with microphones and loudspeakers can be gained but as well on relationships between musicians, the objects they make music with and music itself.

As the idea of what is considered to be a musical instrument is strongly defined by the society in which it emerges, it makes the most sense to look at instruments and their relationship to microphones and loudspeakers within a pre-defined context. For this purpose I go back to the time of the invention of microphones and loudspeakers. There is no one particular date or invention that forms the starting point for these technologies. The entrance of microphones and loudspeakers into music-making practice should be seen as a continuous development taking place through the second half of the nineteenth century and the first quarter of the twentieth century, taking as a possible starting point the year 1857, in which the phonautograph was invented by Édouard-Léon Scott de Martinville*. This was one of the first devices developed for the purpose of notating sound waves. The loudspeaker construction described by Chester W. Rice and Edward W. Kellogg in 1925 (Figure 2.1) in their famous article

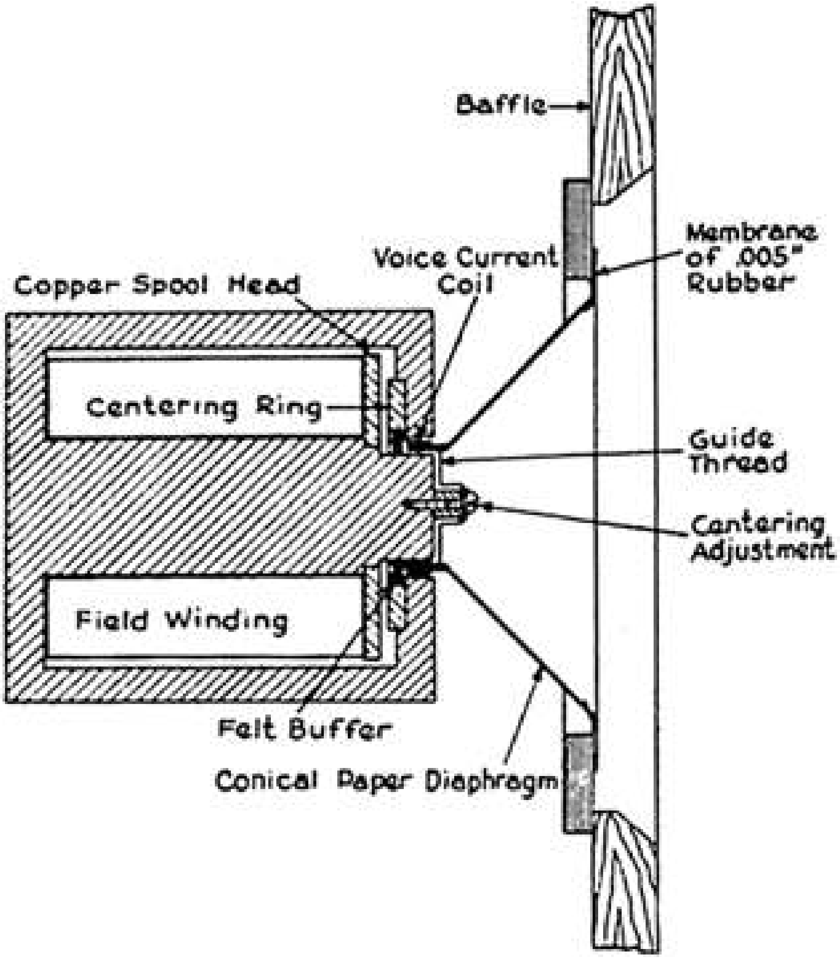


Figure 2.1 A moving coil loudspeaker as developed by Chester W. Rice and Edward W. Kellogg (Rice and Kellogg 1925, 470).

on loudspeakers (Rice and Kellogg 1925) is often seen as a significant stage in the aforementioned development, since this device produced, in combination with electric amplification, a level of sound quality high enough to initiate the mainstream application of microphones and loudspeakers in sound recording, sound reproduction, and sound amplification for radios, concert halls and, a few years later, cinemas.[3] It is between the years 1857 and 1925 that many prototypes of devices, such as the telephone, radio and phonograph, nowadays classified as sound reproduction technology devices, were invented.

To obtain an idea of what was regarded as a musical instrument during this timespan, I examine two concepts regarding the identity of a musical instrument which were in circulation around the beginning of the twentieth century. The first was formulated by music-ethnologists Erich Moritz von Hornbostel and Curt Sachs, who developed what became a famous classification system for instruments at the beginning of the twentieth century (Hornbostel and Sachs 1914), which is still appreciated by many contemporary musicologists.[4] As Hornbostel mentions in an article in 1933 on African sound instruments, 'for purposes of research, everything with which sound can be produced intentionally must count as a musical instrument, and, for this reason, it is advisable to use the term "sound-producing instruments"' (Hornbostel 1933, 129). This definition should be regarded as rather revolutionary in the context of its time, since it implies that everything 'with which sound can be produced' can become a musical instrument. This broad definition of what a musical instrument might be should be seen in the context of Sachs and Hornbostel's ethnological approach. Whereas many earlier definitions had focused on typical Western European characteristics of music, they attempted to include all kinds of instruments without articulating aesthetic boundaries as defined by a specific expectation of what music is. Heinrich Christoph Koch's *Musikalisches Lexikon* of 1802, for example, claims that a musical instrument should produce tones, thus implicitly excluding noises, and therefore also all music cultures that are based mainly on percussion instruments. His remark that the ideal instrument should come as close as possible to the human voice underlines this idea (Koch 1802, 779–780). The second unconventional aspect of Hornbostel's definition is that he draws no predetermined line to distinguish sound from music. According to this idea of what an instrument is, any sound can be part of a musical performance, and no sound is *per se* unmusical. Here again, the ethnological approach, in this case applied to the investigation of African sound instruments, results in a much more open approach as to what an instrument – as well as music itself – might be.

Hornbostel underlines his conviction that the sound should be produced intentionally. The intention of producing sound with these 'sound-producing instruments' can be linked to the idea of the transportation of music, and here I refer back to Tanaka's statement (Tanaka 2000, 389). This idea of musical instruments as transportation vehicles for music can be found in radical form in the work of Hugo Riemann*. He considered the performance of musical works to be a mere transference of the musical proceedings from the fantasy of the composer into the head of the listener (Riemann 1916, 2). Musical instruments are, in this case, nothing more than devices through which music in a certain manifestation may be channelled. Regarded in this way, music's manifestation in sound is not necessarily its only form of existence: reading a musical score, for example, is regarded by many as a way to apprehend the notated musical performance (Heilgendorff 2008, 117).[5]

If I apply Hornbostel's and Riemann's ideas on instruments to microphones and loudspeakers, I have no hesitation in calling these devices musical instruments. They are indeed producing sound, and this sound is produced intentionally, namely in order to play music. Furthermore, if musical instruments are nothing more than transportation vehicles for musical ideas, as Riemann suggests, then microphones and loudspeakers could even be regarded as ideal transportation vehicles for sound – since they are supposed not to add any sound of their own to the music itself and therefore transporting the sound directly between the mind of the composer and the mind of the listener.

As self-evident as the role of the instrument is in music, it also seems quite as self-evident in contemporary society that the loudspeakers in our living room are *not* musical instruments at all. When listening to one of Bach's *Six Suites for Unaccompanied Violoncello* through loudspeakers, most people would probably regard what they are hearing as the music performed by a violoncello, and not by a piece of cardboard, moving forwards and backwards to produce sound waves. Hornbostel and Riemann both developed their ideas on musical instruments when microphones and loudspeakers were still rare. The invention of sound reproduction technology – of which microphones and loudspeakers were essential parts – calls into question their ideas about instruments which had been established by the end of the nineteenth century. Many sound reproduction technologies used in music were indeed, at their time of invention, termed musical instruments. During the first thirty years of the twentieth century, however, a clear division between musical instruments and sound reproduction technology was established. At the end of the 1920s, sound reproduction technologies were able to become mainstream due to electric amplification. The last highly visible element of the technology which could be traced to a conventional instrument – the 'horn' used for amplification – was removed from sound reproduction devices. Due to this development, most people nowadays would never call the act of playing a CD in their living room 'performing music'.

Violins, mixing desks and spoons

The sole function of musical instruments is often to produce music: pianos, guitars, violins and percussion instruments are designed for this purpose. Whereas the origin of all musical instruments must lie in material not specifically created for music making, such as bones, stones, reeds and sticks, they are all adapted in various ways in order to fulfil a musical function. The resulting object is meant to be used for making music, and nothing else. This might be one of the main reasons that the musical instrument character of all objects which otherwise perform functions other than that of making music, but which have been introduced into the creation of music, is often intensely discussed.[6] If music is dependent on musical instruments, and these instruments are the connection between composer, performer and listener (which can very well be incorporated in one person), what happens when music is made with objects that were not created solely to make music? Are they still as good at transmitting the performer's musical expression, as Tanaka proposes? Is a mixing desk a musical instrument? And what about turntables, radios, laptops and sirens? Or spoons, bikes and wine glasses? All these objects have been part of several musical performances, and some of them, such as glasses and spoons, even have a tradition of being used in music for many centuries.[7]

To approach the use of different kinds of objects in music, I propose three categories of objects used as musical instruments. The first category consists of objects that are developed for the sole purpose of making music. Even if they could have another function, for example as decoration in a living room (think of grand pianos), their main intended function is, without doubt, to make music. The second category consists of all devices whose main function is to deal with sound. In contrast to the first category, they are, in general, not identified as musical instruments, since their main function is not to make music, although they are often used to work with sound in several ways. All devices such as radios, CD players, mixing desks and also microphones and loudspeakers belong to this category. The third category includes all other objects used in music that are not associated with sound at all in their main function. Spoons, glasses and bikes are examples in this category.

The principal function of the latter two categories of objects is something other than making music. This does not mean that these objects were not used in musical performances. To compose music for these objects often implies that the artist brings them within the realm of musical instruments. The unexpected use of the object as a musical instrument is seen as an important aspect of the performance. This is also the case for composers and performers working with microphones and loudspeakers. These artists approach such devices *as if* they are musical instruments, frequently even mentioning this explicitly in their scores or writings (see multiple examples in Chapter 4). So if microphones and loudspeakers belong to the second category of objects with which music can be made, then why are these devices generally *not* considered musical instruments? What are the principal functions of microphones and loudspeakers? What would be the necessary treatment required for them to be considered as musical instruments?

Piano lessons or a phonograph: How sound reproduction technologies entered the living room

Evidently, at the time when the devices now collectively referred to as sound reproduction technology were introduced, a division between these devices and musical instruments did not yet exist as such. As pronounced in Hornbostel's definition, everything utilized for the intentional production of sound should be considered a musical instrument. At that time, music could not be made by anything else, and the whole notion that devices other than musical instruments could produce music or, more correctly, *reproduce* music grew alongside the technology which made such reproduction possible.

Musical instruments are specialized in producing certain sounds much better than others, and most sounds (of the almost infinite spectrum of all possible sounds) are unplayable on a specific instrument. Sound reproduction technology was developed not for producing sounds, but for *re*producing all possible sound waves. This is the essential difference, from a technical point of view, between a musical instrument and a sound reproduction device. A good example is the comparison between a piece of music sounding from a player piano (a self-playing piano) and the same composition being reproduced with a phonograph. The player piano is not reproducing sound waves, but reproduces the acts of sound creation according to how they occur in a piano performance. These physical acts of sound creation, as I will call them, are inherent to the characteristics of a musical instrument. Every physical act of sound creation results in the production of sound waves, so every sound can – in theory – be reproduced by sound reproduction technology. This universal approach of sound wave reproduction distinguishes this technology clearly from musical instruments, including musical automata. Sound reproduction devices are designed to reproduce all kinds of sounds by producing similar sound waves and not to produce a specific sound, a task that is performed by musical instruments (see Pierce 1999, 285; Sterne 2003, 71).

Producers of early sound reproduction technologies tried to convince their audiences that their new devices, developed during the end of the nineteenth century, were nothing other than musical instruments. Thomas Edison* himself thought the phonograph would become the greatest musical instrument in the world (Thompson 1995, 142). Many advertisements for phonographs and gramophones promised the consumer that they would be acquiring real musical instruments. A good example is the marketing strategy of the Victor Talking Machine Company, 'during the period from 1906 to 1921 [...] probably the most consistent user of advertising space in the entire United States' (Maraniss 1937, 9). Their gramophone even received a prize for musical instruments at the St. Louis Exposition of 1904 (Siefert 1995, 440). The reason, at the time, for emphasizing that these devices were musical instruments was that musical instruments had always been necessary for the production of music. Using that description in the publicity material of new devices, such as a gramophone, gave the impression that real music was produced by it (Siefert 1995, 432–433). Sound reproduction technologies were supposed to replace the role of the piano in the living room. Instead of young women (most of the time one of the daughters) who performed music on the piano, as was common in the nineteenth century (Blanning 2008, 183), at the end of the nineteenth century, a phonograph could be installed in the living room and perform (!) in the same role. It may therefore come as no surprise that in some advertisements, the gramophone seemed to become the musician itself, as in this advertisement from the 1890s: 'The Berliner Gram-o-phone talks distinctly, sings every song with expression, plays the piano, cornet, banjo, and in fact every musical instrument with precision and pleasing effect' (Sterne 2003, 164). These new devices were all-round performers of music and able to become any musical instrument.

How the early phonographs became not only the follow-up musical instrument in the living room but why they also easily won from the piano is shown by this advertisement from the Klamath Falls *The Evening Herald*. This advertisement is a small history on the development of sound reproduction technology in the first half of the twentieth century: the living room is the realm of the wife, so it was she who had to be persuaded by the music industry (Figure 2.2). To provide music in this room, she can choose out of several musical instruments: a conventional (grand) piano, two


The Autopiano
$625.00 to $800.00

Knabe
Pianos $250.00
to $1000.00

New Victrola
X $110.00

$50.00, $70.00
and $75.00

To the Wife

If you would like one of our fine musical instruments for Christmas, just cut out this ad and fold it into your husband's pocket.

All good husbands and Santa Claus work together and try to give you happiness.

Victrola XI, $130
XIV $200.00

$25.00–$35.00

Convenient Terms

Earl Shepherd Co.
One Business
Music

No Sidelines
507 Main St.

Baby Grands
$725.00 to $1000.00

Gulbransen Trade Mark
Players $495.00 to
to $850.00

Figure 2.2 An advertisement for musical instruments in the living room: grand pianos, player pianos and phonographs (Anonymous 1919).

different kinds of player pianos, and next to it, sold by the same shop and apparently serving the same function, several phonographs. The pianos itself are not only more expensive, but of course someone has also to be able to play the instrument, pricy piano lessons being a premise. With a phonograph you not only paid much less, on top of that music without mistakes was guaranteed.

The instrumental phonograph and the reproducing radio

Two developments resulted in a shift in the perception of new devices, such as phonographs and gramophones, from musical instruments towards sound reproduction devices. First of all, their sound quality was improved enormously by the use of electric amplification. Electric amplification became mainstream in the 1920s and 1930s and made sound films possible, since loudspeakers had become loud enough to radiate sound into a small hall, such as a cinema. Also, radio used electric amplification instead of the traditional horn, as used by phonographs, to project sound. Owing to the introduction of the radio, the phonograph industry lost much of its popularity. A solution was found in using the same amplifying system for phonographs as for radio: since 'the perfection of electrical sound reproduction has produced an instrument whose striking realism has given new life to that industry' (Harbord 1929, 63).

Before electric amplification, the phonograph horn was used for mechanical amplification. The horn is in fact focusing sound waves, not amplifying, but the result is a louder sound for the listener. Since recordings, according to the advertisements, had been already 'high fidelity' from the beginning of sound reproduction,[8] even when using the horn, the company RCA Victor[9] decided to call electric amplification the 'higher fidelity' system. With the introduction of electric amplification, the emphasis was no longer on the musical instrument, as the Victor Talking Machine Company promoted their phonograph, or on the machine as musician, as Berliner had advertised. The performance was not taking place in the same room anymore as the audience: 'The evidence is in what you hear – a new and stunning kind of musical brilliance that almost makes you believe the performer himself is in the room' (Maraniss 1937, 10). The device itself was no longer the performer or a musical instrument itself, as was claimed in earlier years, but transmitted the performance into one's living room: the performance is happening somewhere else, and the machine reproduces a copy of this performance. Concerts of recorded music were performed in people's living rooms, often even including the same habits as during live concerts, including the distribution of programmes and silence during the music (Katz 2004, 57). Due to the emphasis on the technology's ability to copy the reality of a musical performance perfectly, sound reproduction technology was eventually no longer perceived as a musical instrument, but as a neutral transmitter of the sound of musical instruments (Grossmann 2010, 185–192). With the introduction of stereophony in the 1950s, this illusion was even extended: 'stereophonic techniques enable the listener, in his strategically placed seat, to evoke or extinguish a panoramic view over something larger than himself [the orchestra, CvE]; thus, at a flick of the wrist, a bourgeois ideal–to master the world on a living-room scale–is adequately realized' (Raaijmakers 1971, n.p.). The earlier representation of phonographs as delivering a live performance, just like an instrument or a performer, ultimately led to a division between sound reproducing machines and musical instruments.

Aside from the better sound quality, probably an even more important reason that sound reproduction technology came to be regarded as belonging to a category of its own was the increasing popularity of radio during the 1920s. Whereas the first transmission of regularly scheduled programmes intended for reception by the general public occurred at the beginning of 1921 in the United States (Whittemore 1929, 6), by the mid-1920s more than 1000 radio stations had already been licensed (Harbord 1929, 61). The radio had a totally different relationship to live performances in comparison with the gramophone. Whereas the same record could be played again and again in the intimacy of the living room, and the listener was, to a certain extent, still managing the performance by choosing starting and stopping times, the radio connected the listener to a musical performance happening somewhere else. The music heard on radio was often performed live in a studio. Even when records were played during a radio show, this was often done with a certain atmosphere of live music, such as through announcing the recording. Radio had a continuous timeline, and if you disconnected and reconnected later, you had missed part of the show. Listening to the phonograph resulted in a performance happening in your living room, but listening to the radio connected you to a performance happening somewhere else. It is probably this difference that caused the radio to become thought of as a reproduction device instead of as a musical instrument: 'The aim of broadcasting is obviously truth – the life-like reproduction of the original performance' (Fitchew 1935, 889). The sound produced by the radio was not connected to the device anymore but to the location where the performance was taking place. The radio was conceptualized as connecting the listener with the performance 'as an ideal of instantaneous transmission and reception, a communication without meditation' (Kahn 1992, 20).

One proof that the radio was not seen as a musical instrument may be found in several court judgments (Anonymous 1930, 343; Anonymous 1931, 1045). In both cases, the court argues that the radio is not making any sound of its own: 'a fundamental idea is contained within the definition of a musical instrument. This is the capacity of the instrument in and of itself when properly operated to produce the musical sound. A radio cannot do this. The musical instruments in the distant station, not the radio, produce and initiate the music within the definition before mentioned' (Anonymous 1930, 343).[10] Technically speaking, this is absolutely incorrect, since nothing else is making sound than the radio's loudspeaker(s). Whatever the radio is playing, the loudspeaker is the only sounding object. The seminal source of the sound, though, is, as the court states, the musical instrument in the distant station.

As many authors agree, these new devices did change our relation to sound extensively, due to their ability to reproduce sound.[11] The changes in music perception cannot be attributed only to the use of sound reproduction technology, but should be related also to changes in musical performance practice such as the *Konzertreform*. With the invention of sound reproduction technology, instruments were no longer alone in making musical sound, or as Hornbostel calls it, making sound with the intention to create music. For the first time, when listening to music, one had to ask oneself whether this music was produced by a musical instrument or whether sound waves similar to the sound waves produced by a musical instrument were being reproduced by a sound reproducing device. A major change in musical performances was the disappearance of the need to have musicians performing on musical instruments in order to hear any music. New inventions, such as telephones, phonographs and radios, made it possible to listen to music everywhere, no longer demanding from the audience that they share time and place with musicians and their instruments.

Semantic acts of sound creation

Agreement as to what a musical instrument is, and which devices belong to the category of sound reproduction technology, is much less ambiguous today than in the early twentieth century. By comparing the playing of two kinds of musical instruments, namely clarinet and organ, and correlate these to the operating of a CD player, I will compare what types of action are needed to play the instrument and what types of sound creation acts the listener perceives.

Playing the clarinet involves adding breath to create energy for air pressure waves and moving fingers to shorten or lengthen the pipe, with the help of keys that facilitate the closing and opening of holes in it. Whereas a clarinet player still has direct contact with the sound production, since it is his or her breath causing the sound, an organ player is already further removed from the sound production process. The 'breath' for the organ is supplied by an extra mechanism, today often controlled by electric motors; in earlier days, human-powered. By pressing just one key on the keyboard, several pipes may be simultaneously activated, the equivalent of being able to play several clarinets simultaneously with the use of just one finger. From this point of view, the physical movements of an organ player can be interpreted as more detached from the sounding result than the movements of the body of a clarinet player. Pushing the play button on a CD player, however – an action not unlike pressing a key on the organ or clarinet – generates an entire piece of music. The 'breath' is supplied by electricity. Whereas the difference between playing a clarinet, an organ and a CD player, in the analysis above, seems to be nothing more than a slight modification within the same category of performance, the clarinet and organ are generally considered to be musical instruments whereas the CD player is normally seen as a machine.

The reason clarinets and organs are classified as musical instruments and CD players as machines may be the following: during the playing of a clarinet or an organ, no other *acts of sound creation* are perceptible than the ones caused by the movements of the performer, whereas listening to a CD will result in the perception of manifold acts of sound creation. In the case of the CD player, the intention of sound production, as Hornbostel would call it, is more clearly linked to the referential character of the sound waves themselves – that is, to the recorded musical instruments – than to the physical act of sound creation itself, which consists of the mere act of pushing the play button. When playing a CD, the musical expression which is transmitted – a defining function of musical instruments according to Tanaka – arises not from the act of pushing the play button of the CD player but from the acts of sound creation recognizable in the sound waves themselves. The act of pushing the play button is so weakly linked to the resulting sound, as compared to all the acts of sound creation perceptible in the recorded music, that often neither the CD player nor the amplifier nor the loudspeakers will be regarded as (part of) the musical instrument. I term these referential characters of sound waves towards the seminal source of the sound – for example the violin playing recorded on the CD – the *semantic act of sound creation*. The physical acts of sound creation remain of course nothing else than the vibrations of the loudspeaker diaphragm.

Hearing voices through the noise: Completely satisfactory recordings in 1902

To recognize the semantic acts of sound creation – which instrument is playing on the recording – sound reproduction technology itself should be not perceivable. If one listens to wax cylinder recordings from the end of the nineteenth century, it is almost incredible that through all the loud noise, one is able to recognize any music at all. How is it possible to distinguish between recorded sound (the semantic acts of sound creation) and the noise of the sound reproduction device itself?

What follows may seem contradictory to my previous discussion of the phonograph being regarded as a musical instrument. At the beginning of the twentieth century, the phonograph was seen as being able to reproduce all musical instruments. However, by this I do not mean to suggest that those listening to a phonograph performance did not recognize that the instrument ‘played by the phonograph’ was a violin. The identification and differentiation of which sound on the recording belongs to which musical instrument – the referential potential of the sound waves – and which sounds are added by a sound reproducing device – all the humming and noise on the recording – were already practised very early, when sound reproduction quality was still very low. The capability of human beings to focus on the music in these recordings and to minimalize the perception of noise is partly a result of what is called Gestalt laws of grouping. During listening, common fate is one of the dominant grouping principles, and we therefore hear partials which frequencies move in parallel, as belonging to the same sound ‘cause’. The cause is the vibrating object producing sound waves, such as a violin. We also tend to give these groups of partials more attention than random sound in which the frequency and amplitude of the partials do not relate to each other. As the cognitive scientist Roger Shepard mentions, these grouping laws are ‘“wired into” our perceptual machinery. They do not have to be learned by trial and possibly fatal error, because they generally hold in the real world’ (Shepard 1999, 34). Our brain easily distinguishes between noise produced by the sound reproduction devices themselves and music created by musical instruments. With the Gestalt laws of grouping in mind, it is obvious why this happens: the music on these early recordings is melodic and rhythmic. The partials of the music are easy to distinguish from the noise on these recordings, since all these partials change together in pitch and rhythm, as opposed to the noise of the sound reproduction device. The partials of noise do not have a particular relationship to one another, and almost no collective changes in pitch or rhythm take place. When listening to old wax cylinder recordings which have an extremely high amount of noise, it even proves difficult to try to ignore the music that is played and focus solely on the noise. To be as recognizable as possible, the music documented on these early recordings focused not only on melody and rhythm but also on qualities differentiating the sound produced as much as possible from the noise of the machine. Singing was especially suitable for recordings, particularly by opera singers with trained voices. Enrico Caruso's voice remained clearly recognizable against the noise of the needle on the surface of the record. As early as in 1902, his recordings were already considered to be 'completely satisfactory', probably because 'Caruso's strong tenor voice (with its baritone quality) helped to drown out the surface noise, so that even on the inadequate apparatus of the time, his records sounded rich and vibrant' (Chanan 1995, 30). The fact that already at a very early stage the phonograph was able to give the impression of a recording of a specific instrument underlines that aesthetically acceptable sound reproduction was already possible.

Electricity, bodies and diaphragms

Whereas a phonograph functioned entirely without, electricity was essential for telephones to be able to transport sound waves from one place to another. The significant difference between mechanical and electric sound reproduction technologies is this transduction into electricity, since it creates the possibility of eliciting changes in these waves between the input (the microphone) and the output (the loudspeaker). As soon as it has been converted to electricity, a recorded sound can be processed in numerous ways. Any sound characteristic can be changed in between microphone input and loudspeaker output. All mechanical sound reproduction technologies are connected to the material which stores or transports them: there is no possibility of changing the relationship between what was recorded and what is reproduced, since both sides of the process are connected to the same material.[12] This is best demonstrated by early sound reproduction technologies, such as the phonograph: the same wax roll is used for recording the sound as for reproducing it. As long as the subject of research is sound reproduction, this distinction is not important, because there should be as little alteration possible between the sound that comes into the microphone and the sound produced by the loudspeaker. Jonathan Sterne, for example, sees all sound reproduction technologies united in the use of what he calls transducers from sound into something else and then back to sound, whether using electricity or any other medium, such as tinfoil or wax (Sterne 2003, 22). His research focuses, however, on telephony, radio and recordings, all of which have as aim to create the least possible alteration, or at least the impression of no alteration, between the sound at the input of the sound reproduction technology and the sound at the output of that technology. My view on this topic is from the perspective of a composer, and as such, I often regard changes between input and output sound as one of the principal goals. An electric current is easily modified according to other principles than mechanical laws, and musicians and composers gratefully started to use this feature.

The introduction of electricity as a sound source has been commented upon by many as one of the most influential changes in music-making which took place in the last centuries. Konrad Boehmer* goes as far as to call this the *terza prattica* (Boehmer 2004, 159), giving the introduction of what he calls 'an authentic electric music'[13] the same weight as the paradigm shift from *prima prattica* to *seconda prattica* in the seventeenth century.[14] 'What was previously characteristic of the breakthroughs of the *prima prattica* and the *seconda prattica* is no less valid for the historical perspectives of a *terza prattica*: there can be no new art forms without a new understanding of the world, without an understanding of a new world' (Boehmer 2004, 168). Boehmer finds the development of 'an authentic electric music' as important as the introduction, more than a 1,000 years ago, of the notation system for music. Clearly, according to Boehmer, this new practice of electric music has not yet been fully developed.

The philosopher Peter Szendy observes that the use of electricity in music generates a totally new relationship between the music making 'bodies', seeing not only the musician himself or herself as a body, but the musical instrument as well. This results in a totally different coupling of these bodies from what had been possible without electricity (Szendy 2002, 133). Whereas, with a mechanical musical instrument, the player needed to be within a certain proximity to the instrument, with electricity the instrument can be played at a distance without having to take any laws of classical mechanics into account. An organist, for example, can control organ pipes at enormous distances with the help of electricity. In electronic music, this can become even more complex, with one single keyboard many different synthesizers or sound processings can be controlled. Various authors take the elimination of the relationship – unavoidable in earlier times – between the musician's movements and the quality of the resulting sound, due to the use of electric sound production, as a starting point in the book *Klang (ohne) Körper* (Harenberg and Weissberg 2010a, 7). All these authors confirm that the introduction of electricity not only changed the relationship between the musician and his or her instrument, but that the whole praxis of music was modified.

Microphones and loudspeakers are obviously important agents in all these new possibilities for music, situated as they are between the material world of air pressure waves and the virtual world of electricity. It has become increasingly rare for a piece of music not to confront the listener with microphones and loudspeakers. Most music heard these days comes to the listener in the form of sound waves produced by one or more loudspeakers, whether from a CD played at home, amplified instruments during a concert, or an MP3-player with earphones on the go. In fact, all of the different physical acts of sound creation existing in music made by musical instruments are diminished to just one general action, namely the vibration of a very thin loudspeaker diaphragm. Whereas this sound production method is the same for nearly all music (excepting unamplified live music performances), the perceived acts of sound creation are rarely attributed to these thin diaphragms, but rather to the recorded or amplified instruments.

Reproducing: One sound system for all music

To be able to analyse and compare musical situations using microphones and loudspeakers, I divide the use of microphones and loudspeakers in the context of musical instruments in four different approaches. These approaches are named *reproducing*, *supporting*, *generating* and *interaction*. I discussed most of the characteristics of the *reproducing* approach in Chapter 1, in my analysis of the reproduction of music using microphones and loudspeakers. What is most remarkable about this approach is the premise that one general sound system, such as the common stereo loudspeaker system in a living room, is able to reproduce all music. Most importantly, in this scenario microphones and loudspeakers should act like transparent devices, adding no sound of their own, thus reproducing a musical performance with 'high fidelity'. Since then this quest for high fidelity proved to be endless, since every new invention in the realm of microphones, loudspeakers or any other aspect of sound reproduction technology has as its goal reproducing the music performance with ever higher fidelity. A performance heard through loudspeakers should not be thought of as being produced by loudspeakers: the impression of a concert happening behind curtains is the main aim of a good recording. Especially in the case of the classical music recording industry, many recordings profess to reproduce the concert experience in the living room. There should be no significant difference in the experience of listening to a symphony by Beethoven at home through a hifi-system to that of listening to the same symphony in a concert hall performed by an orchestra. This *reproducing* approach is very common, given that a recording might be called the normal way to be confronted with music nowadays, replacing the live performance, as practised before the introduction of sound reproduction technology (Gracyk 1997, 139).

Supporting: The same sound but louder

Apart from *reproducing* already existing music performances, microphones and loudspeakers are also used in another constitutive approach: they are involved in what I term *supporting* the sound of musical instruments. Whereas sound reproduction brings music into people's living rooms, the *supporting* of musical instruments by microphones and loudspeakers happens mainly on the concert stage. The role of these devices when supporting a musical instrument might be compared to the soundboard of a piano or the corpus of a violin. The soundboard or corpus are an essential component of the instrument, and are also at the same time reliant on other parts of these instruments. The main function of the soundboard of a piano is to transmit vibrations produced by strings that have been hit by a hammer. Soundboards are amplifying the sound, resulting in a louder, but shorter sound, since no additional energy is added, Due to the greater surface of the soundboard in comparison with the surface of the strings, the vibrations will be easier transformed to air pressure waves, and thus sound louder. In electric amplification not a soundboard is used, but a loudspeaker diaphragm. Since this loudspeaker is controlled by an alternating electric current, the vibrations of the diaphragm can be enlarged and amplification of the signal without shortening the sound is possible. The piano would clearly be incomplete without the soundboard, but something would still be sounding (albeit much softer and shorter than the customary piano sound). Conversely, the soundboard alone cannot function independently; it is supporting the instrument, in this case, the piano. Based on this understanding, I define the *supporting* approach for microphones and loudspeakers as manifested, for example, in electric guitar or voice amplification: they can be considered as a supporting component of an instrument, whose core acts of sound creation are produced by the guitar strings or vocal chords.

At the beginning of the twentieth century, when electric amplification was introduced to support musical instruments, microphones and loudspeakers were not yet seen as adding any sonic characteristics to the instruments they were amplifying. The main aim for using microphones and loudspeakers on stage seems to have been the creation of musical instruments able to produce sound at higher volumes. This was needed since audiences had grown larger, and thus became noisier, and performances took place in larger halls (McSwain 2002, 189). This was part of a development already going on since the beginning of the nineteenth century. Many new inventions in acoustic instrument design were introduced during that period in order to make instruments louder. A good example is the metal frame of a grand piano, making it possible to greatly increase string tension and, therefore, to produce more volume. In this quest for louder musical instruments, amplification of sound with the help of electricity was introduced at the beginning of the twentieth century. As John J. Comer* states in his patent of 1910, his invention is designed as 'the receiver of an instrument for reproducing or transmitting musical vibrations' (Comer 1910, 1). What Comer calls a receiver is nothing other than an early loudspeaker. The name 'receiver' is derived from the receiver of a telephone, the part through which one hears the voice of the other person. Comer further argues that this receiver 'has for its object to produce sounds of greater volume and of purer and truer tone than heretofore' (Comer 1910, 2). Comer mentions that the sound of the instrument changes to what he calls 'a purer and truer tone'. Instead of regarding this as an alienation of the main instrument, Comer regarded the amplified guitar as even closer to the 'true' instrument than the unamplified version. As was described in many patents as late as the 1930s, the sound of the amplified instrument would be the *same* as the sound of the unamplified instrument. The only difference would be a louder volume (McSwain 2002, 193). This technological addition did not have as its aim that of changing the character of the original instrument. The developments in music, such as, for example, the highly modified construction of an electric guitar as compared to an acoustic guitar, or the different singing techniques developed as a result of voice amplification, clearly reveal that this technology had much more impact than solely that of increasing the volume of already existing musical instruments.

Within the concept of the *supporting* approach, I include those loudspeakers used in instruments invented during the 1920s, such as the theremin, trautonium and ondes Martenot, although they are a special case. These new instruments all use electricity to produce sound. The use of loudspeakers was essential, since only thus could the sounds become audible. Unlike voice or guitar amplification, the loudspeakers are an indispensable part of the musical instrument itself. Instruments like the theremin were among the first ones which needed a loudspeaker in order to be able to produce sound at all. In the realm of sound production, these instruments were important inventions, making audible sound entirely with electric circuits. Sometimes the design of the loudspeakers used, for example the three loudspeakers of the ondes Martenot, reveals that the loudspeaker was seen as the sound producer for these instruments and not as a neutral transducer from electrical signal to air pressure waves. Of the three loudspeakers of the ondes Martenot, one is prepared with a metal plate (called *métalique),* a second with sympathetic strings (*palme*), and the main loudspeaker contains some metal springs usable for reverb (*résonance*) besides a plain loudspeaker (*principal*) (Cramer 2008, 142). These objects resonate due to the air pressure waves produced by the loudspeaker diaphragm and, so doing, create additional sounds. The ondes Martenot loudspeakers are remarkable for their individual design. Another remarkable invention in this realm is the Leslie tone cabinet, using rotating loudspeakers and designed for emitting the sound generated with a Hammond organ (Limina 2002, 15–17).

The aim of the inventors of these new instruments using new technology was to prove that their inventions were equal to conventional musical instruments. The idea of what an instrument is did not change at all as a result of these new inventions; quite the contrary. To prove that the theremin is efficient in transmitting the performer's musical expression – coming back once more to Tanaka's definition (Tanaka 2000, 389) – just as the violin or violoncello are, pieces written for those older instruments have been played on the theremin. A talented violin player, Clara Rockmore, met Lev Termen, the inventor of the instrument, in the 1930s, and learned to play the theremin, performing well-known pieces, by Tchaikovsky and Saint-Saëns, originally composed for violin or violoncello (Cramer 2008, 134–135). With these compositions an immediate comparison could be made by the audience, since they already knew this standard classical music repertoire. An account of the first concert of a chamber orchestra of theremins at the Carnegie Hall in 1932 mentions the performance of popular pieces like *Aase's Death* (1875) by Edvard Grieg and the prelude of Richard Wagner's *Lohengrin* (1850). This was seen (or better said heard) as a proof that a performer could still perform the well-known music repertoire in the same expressive way on the new instrument. This 'foreshadows a new era in which electrical musical instruments will take their place beside such time honoured instruments as the violin and the piano' (Anonymous 1932, n.p.). The theremin was presented as an instrument that was as 'musical' as all other existing instruments. Although 'the audience was keenly interested in the new timbres and acoustical effects obtained' by these new instruments (Anonymous 1932, n.p.), they did only hear music that was more than fifty years old.

Nonetheless some advantages compared to conventional musical instruments were remarked as well. By comparing the quality of loudspeakers as sound producers with conventional instruments, it was mentioned, for example, that 'the surface of sound-emission from the speaking-cabinet and therefore its carrying power is more circumscribed than that of the Pipe Organ; but there is compensation in the fact that these speaking-cabinets[15] may be placed in the building where you will and as many as you will' (Galpin 1937, 81). The possibilities of the multiplication of sound sources as well as the loss of the constraint that sound is bound to the place where it is shaped were explored in-depth by composers and musicians in the second half of the twentieth century.

Transparent technology

The idea of only changing the volume of the instruments by amplification, without changing anything else – for example the tone colour of the instrument or the spatialization of the sound – can be seen as corresponding to the idea of the reproduction of a concert in the living room, since here, again, the microphone, amplifier and loudspeaker should remain 'inaudible'. Exemplifying this, in audio-engineering circles a perfect amplifier – that is one that distorts the electrical signal not at all – is commonly called a straight wire with gain. Inaudible sound reproducing technologies are often described as being transparent. Sterne describes this acoustic transparency in sound reproduction as 'ideally, the medium would disappear, and original and copy would be identical for listeners' (Sterne 2003, 256). Although transparency is a word from the visual domain, I do think it is more suitable than words such as inaudible – the loudspeaker is audible of course just not as such – and there is no real replacement in the acoustic world for transparency.

When I speak about this transparency in the reproducing and supporting approach, I must underline that I am not referring to technical possibilities, but about how the technology is perceived or even the cultural consensus of how it should be perceived, which means, in this case, that the technology should not be perceived at all. The music should sound as if produced by a human body interacting with a musical instrument, not with technology. Already this distinction between technology and musical instrument reveals the complication of this division, because is not every musical instrument a technological construction itself? Innovations in musical instrument design are often contemporaneous with technological developments occurring in fields not related to musical practice at all. The knowledge contributing to the development of valves for trumpets and horns as well as gear, cranks and levers for timpani was transferred from technologies unconnected to music (Bowles 1999, n.p.). A piano is built through the application of an enormous amount of technology and 'is a machine. That may not be the first word that comes to mind to define the instrument, but is perhaps the most inclusive [...]. A machine accomplishes work, that is, it applies energy to some end. The piano's energy[16] produces musical sound vibrations' (Good 2001, 2).

The idea of an ‘inaudible’ technology is older, however, than sound reproduction technology. The technology of an instrument, such as the operation of the valves, keys and pedals, should also be inaudible. The movements of the keys and pedals of, for example, a grand piano should as a rule not be heard during a conventional piano performance. The same can be said about the supporting role of microphones and loudspeakers: hearing a singer amplified through microphones, amplifier and loudspeaker rarely results in the audience perceiving a musical instrument consisting of singer, microphone, amplifier and loudspeaker. The main perception will remain that of somebody singing, whatever other technology is added to the voice. The sound produced here is a result of the incorporation of all elements involved: the voice of the singer, the microphone, the amplifier, the loudspeaker and even the performance space. The sound produced is affected by a combination of all of these elements, but the semantic acts of sound creation are associated with only the singer.

In both approaches, the concept of *reproducing* and *supporting* what a musical instrument does or its role in creating music does not change as a result of the introduction of microphones and loudspeakers. These devices function simply as a new addition to an existing musical instrument. The additions might be seen as modifications of the instrument, just as the change from wooden frame to metal frame in grand pianos also changed the instrument’s volume and timbre; however, the instrument remained a piano.

Although the idea of transparent technology is similar in both *reproducing* and *supporting*, my reason to divide this into two different approaches is that microphones and loudspeakers are treated quite differently. For *supporting*, both microphones and loudspeakers are part of the instrument. Instruments often have their own loudspeaker (think of electric guitar amplifying systems), which results in at least as many loudspeakers on stage as there are instrumentalists. The loudspeaker is placed close to the sound-shaping component of the instrument, so that the sound comes from the same location as the instrument. Loudspeakers designed for *supporting* the sound of musical instruments do not respond as linearly as possible to all frequencies, but are tailored to respond in certain ways with certain frequencies. So-called guitar amplifiers are often a combination of an amplifier and several loudspeakers, designed to produce a specific sound. As careful as a player is in choosing the guitar, an amplifier is chosen as well due to its sound characteristics. Microphone use falling within the *supporting* approach category is also often adapted for the instrument: when used for support, they are often built into the instrument, as is the case with the pick-up for the electric guitar, for example. Instrumentalists and singers often have preferred microphones for amplification, chosen for the sound colour they add. In addition, the movements that singers make when using a microphone – closer or further from the mouth – could be analysed as an instrumental playing technique. Not only the level of amplification varies due to these changes in distance between mouth and microphone but the frequency spectrum of the sound – often called sound colour – does as well, depending on the characteristics of the microphone.

Contrary to the use of loudspeakers in the *supporting* approach, in the *reproducing* approach the loudspeaker systems should not be specialized for reproducing specific sounds, but be as flexible as possible, and ideally able to reproduce all kind of sounds at uniformly high quality. Identical loudspeakers might be used for reproducing instrumental settings as divergent as piano solo, jazz combo, pop band, or even an entire symphony orchestra. All this music can be listened to through the same loudspeaker pair in the living room. Even if the system is modified by changing to a 5.1 audio system, for example, the main approach remains: all music is listened to through one kind of loudspeaker set-up; no changes are required for different musical styles or instrument combinations. What these loudspeakers reproduce is a so-called phantom image of the musical performance, the 'screen' on which sound is projected. In between the loudspeakers phantom sound sources are placed: for example, a violin on the left and a violoncello on the right, whereas the viola sounds more towards the middle. These sound sources are called phantom, as there are no real sound sources in between both loudspeakers. The sound seems to come from a certain direction, but this effect is in fact due to the mix of sound radiated by two or more loudspeakers.

To produce recordings whereby all kinds of music become playable through just one system, many different microphones are needed. The universal method found in the loudspeaker set-up for the *reproducing* approach is not applicable to the use of microphones in this approach. The microphones are not part of the instrument, as they might be considered when used for the *supporting* approach, but their function could better be compared with that of an ear for each specific instrument. The sound of every single instrument is picked up by these 'ears', often by using at least one microphone per instrument, and the microphone is chosen due to its specific characteristics and suitability for a particular instrument. Microphones are not only used specifically for certain instruments, but often some of them are also used for obtaining a so-called stereo image, an overview of the acoustic information of the performance. These microphones will produce phantom images of the recorded instruments in between the loudspeakers. The final recording is a mixdown of all these different, highly specialized 'ears', reproduced on a universal loudspeaker system (Bartlett and Bartlett 2002).

The record as a copy of the concert and the concert as a copy of the record

The *reproducing* and *supporting* approaches are both models for the possible relationships between microphones and loudspeakers, and musical instruments. The recording, intended as a reproduction of a concert experience, soon became an art form in itself. With continual attempts to create the perfect concert recording or transmission, better than one would ever be able to enjoy during a real concert, using all possibilities of the new technologies, the recording becomes a new way of perceiving music instead of a reproduction of a concert experience (Thompson 1995, 160). Attending a concert in your own living room becomes the ideal experience. What was meant to be a copy of a real experience has become a reality of its own. Recordings are produced by combining many different fragments of several performances, so-called 'takes'. Even in alleged live recordings, various live takes are combined, and often the result is a performance that would not have been possible in a live concert situation. Mistakes can, for example, be cut out of a recording, resulting in an ideal interpretation of the piece. As Hans-Joachim Braun states, 'improved sound reproduction technology has rather increased the difference between sound recording and sound reproduction than diminished it' (Braun 2002, 22). As some argue, due to the 'perfect' interpretations on recordings, concerts themselves have changed as well. It is no longer desirable for interpretation to contain spontaneous elements anymore, since the audience must recognize the piece according to the recording, which they had heard at home. 'The reason that this streamlined performance comes to replace interpretation and its elements of spontaneity is precisely to ensure that the concert performance shall indeed be a copy of the record, and the concert-goer will not be disappointed' (Chanan 1995, 118). The same proves true in the case of the *supporting* approach. The development from acoustic to electric guitar is probably one of the best examples of how utilizing amplification to support the sound of an instrument resulted in a completely new instrument (McSwain 2002). Another good example is the human voice. Singers no longer needed special singing techniques in order to fill a whole opera house, when their voice was amplified with the help of microphone technology. Speaking or even whispering could be utilized as elements of a voice performance. The practice of singing, therefore, changed enormously (for a more general discussion of this subject, see Lockheart 2003; Penman 2002).

Although numerous instruments changed owing to the introduction of microphones and loudspeakers, the *reproducing* and *supporting* approaches of microphone and loudspeaker use did not have a significant impact on the role of musical instruments in music. In fact, they even bolstered the conventional idea that music needs instruments and, in a certain sense, it even narrowed down the concept of what music and musical instruments could be. Recorded instruments often had to sound as closely as possible to the real musical instrument. The use of microphones and loudspeakers in music, and sound reproduction technology in general, was not developed in the first place to transform music, but rather to make music available to more people, especially in the private sphere of the living room (Freire and Palombini 2003, 67). The philosopher Theodor W. Adorno writes about the phonograph in his text *The Form of the Phonograph Record*: 'The phonograph record is not good for much more than reproducing and storing a music deprived of its best dimension, a music, namely, that was already in existence before the phonograph record and is not significantly altered by it. There has been no development of phonographic composers' (Adorno 1990, 57). It is indeed remarkable that there was nearly no music developed especially for the phonograph or for the radio during the 1920s and 1930s, although many proposed this (see Freire and Palombini 2003, 68; Raven-Hart 1930, 138–139; Swainson 1931, 396). The *Grammophonmusik*, composed by Paul Hindemith around the 1930s in Berlin, was an exception.[17] It was only after the Second World War that people such as Pierre Schaeffer* would compose with the use of gramophone records. An entire DJ and turntablist culture would emerge during the second half of the twentieth century, and working with reproduced music in general (often in the form of what is called 'sampling' nowadays) would become a common phenomenon. I do think, though, that the fact that hardly any music was composed for the new sound devices, such as phonographs and radios, during the 1930s, is another reason that these devices came to be considered less and less as belonging to the realm of musical instruments. Alterations in music composition itself, as related to the invention of sound reproduction technology, mainly commenced after the Second World War.

Generating: Music without musical instruments

Around the 1950s, a new aesthetic attitude towards the use of microphones and loudspeakers in musical creation came into existence. The main aim of this approach was no longer to use microphones and loudspeakers simply for *reproducing* or *supporting* conventional musical instruments. On the contrary, this time the principal question was: what kind of music can only be heard or come into being through loudspeakers? What if an electrical signal, and no longer the movements of performers upon instruments, is taken as the starting point for sound?

The possibilities of new sound reproduction devices were regarded as promising for composers already before the Second World War. Many artists had been searching for new sounds during the first half of the twentieth century. They were looking for new material in music – not new as regards pitch or rhythm, but new in the realm of timbre. Composers as disparate as Kurt Weill and Edgard Varèse* asked for a music that took into account the possibility of producing new sounds with the newly invented devices. Varèse wanted to have 'a sound-*producing* machine instead of a sound-*reproducing* one' (cited in: Freire and Palombini 2003, 68), and Weill imagined 'a host of new, unheard sounds that the microphone could produce in artificial ways if sound waves were raised or lowered, superimposed or interwoven, faded out or born anew' (cited in: Freire and Palombini 2003, 69).

Conventional musical instruments were no longer of any use in music invented with these new devices, as is described by Dorothy Swainson: '[Composers, CvE] may be able to eliminate interpreters altogether and write their music with a graving tool directly on to the wax with mathematical precision and certainty of obtaining the desired result regardless of whether their conception is producible on any known musical instruments or not' (Swainson 1931, 396). This idea relates to Riemann's idea that musical instruments are a mere means of transportation for musical ideas. Riemann and Swainson both see instruments as possible disruptions of the musical works conceptualized in the heads of composers. Without needing musical instruments, the composer should be able to literally design, or sculpt, the sound he or she hears in his or her inner world. Konrad Boehmer claims that for an authentic electric music, 'an uncoupling from the idea of an "instrument"' (Boehmer 2004, 161) is needed.

This idea of creating music which no longer has any connection to existing musical instruments nor needs musicians to perform on them forms the third approach, which I term *generating*. The sound is produced by the loudspeakers and could not exist without them. A musical instrument is not present at all in this music. Whereas the sound of electronic instruments, such as the theremin, also need a loudspeaker to become audible, the difference lies not in the *method* of sound production, which may be the same (both are produced electronically) but rather in the *acts of sound creation*, which diverge.

Whereas the examples of the *generating* approach are very rare before the Second World War, this approach began to flourish at the end of the 1940s and the beginning of the 1950s. As Dick Raaijmakers* points out, the composer has become a non-instrument-bound sound organizer,[18] a function which simply did not exist before. Conventionally, the instrument maker was inventing new instruments and therefore dealing with the relationship between music and technology. After the Second World War the composers themselves started to work with autonomous electronic sound (Raaijmakers 1990, 8–9). Karlheinz Stockhausen* was one of these composers, advocating new paths for music during the 1950s and claiming that composers should compose their own sounds instead of composing for sounds produced by already existing musical instruments. Stockhausen wanted to free music of what he calls the 'dictatorship of the material' (Stockhausen 2004, 371), which was, for him, the sound of conventional instruments. In his eyes, compositions for piano, violin or clarinet could never be entirely new, invented from scratch, by the composer, since the timbre – also often called sound colour – is predefined by these instruments. Timbre should become composable as well.

In his compositional technique, Stockhausen searched for a method to integrate 'all the characteristics of the material into one uniform musical organization' (Stockhausen 2004, 372). According to him, characteristics of the material are pitch, loudness, duration and timbre. He aimed to use the same principle of organization for all these characteristics. In applying serial composition techniques, the pitch and loudness of sounds could be organized rather easily in this way, but as long as one was composing with conventional musical instruments, this remained impossible with timbre. Pitch and loudness can be given a place in a hierarchy, from low to high and from soft to loud as well as scaled into all kind of divisions, by using, for example, microtonal distances. This, however, does not work for instrumental timbre, since a hierarchical arrangement cannot be effected within this domain, nor can an equal division of different timbres be devised. When considering timbre, there is no physically measurable equivalent of high and low or soft to loud: you cannot order the timbres of a piano, a violin and a clarinet in a mathematically meaningful row. But composers such as Stockhausen 'wanted absolutely pure, controllable sounds without the subjective emotional influence of "interpreters"' (Toop 1979, 380).

To compose timbre instead of relying on the timbre of conventional musical instruments is possible if timbre is considered to be an addition of several single frequencies. The sound of an instrument is dependent on its physical material and the way this material is brought into vibration. The material reacts to the energy input by vibrating. Specific patterns of vibrating create the so-called timbre or sound colour of the instrument. These vibrations of the material give rise to sound waves in the air. At the beginning of the nineteenth century, the mathematician and physicist Jean-Baptiste Fourier proved that every wave could be represented by a combination of a multitude of single-frequency waves, called sine waves. These single frequencies are what are normally called the partials of the frequency spectrum of a sound. This spectrum is changing over time, and so is the representation by sine waves. This model is important for composers interested in generating sound waves to be produced by loudspeakers, since it allows for the possibility to create complex sound waves from scratch.

A pure sine tone cannot be produced by any conventional musical instrument, since the physical material of the instrument vibrates with more than one single frequency.[19] With the invention of transducers for converting electricity into air pressure waves, an electric sine wave generator could be made audible through a loudspeaker, since a loudspeaker is generally designed to add the least possible of its 'own' sound to the sound wave as represented by the electrical signal that drives the loudspeaker-coil's movements. When the loudspeaker is driven by an electrical signal in the form of a sine wave, the sound emitted by the loudspeaker will itself be very close to a sine wave. By adding together many sine tones, composers could have full control over the spectrum of the sound. This aggregation of sine tones became a very common technique in electronic music, and is usually described as additive synthesis. All manner of combinations unavailable in the frequency spectra of musical instruments could be tried out and, at least in theory, composers could entirely compose their own sounds.

Conceptually, Stockhausen was strongly influenced by Karel Goeyvaerts*. As the musicologist Richard Toop argues, it was not Stockhausen who initiated the idea of composing sounds using sine tones, but Goeyvaerts, with whom Stockhausen had an intense correspondence during the early 1950s (Toop 1979, 386). Goeyvaerts produced several electronic compositions during this time. One of these pieces can be understood as revealing the core idea behind the *generating* approach: a music without any musicians should be made without any movements, even excluding the movements of tape. In Goeyvaerts's *compositie nr 4 met dode tonen*, the music is generated from nowhere. This piece exists only as a score, since it is a conceptual idea that cannot be transformed into sound.[20] Goeyvaerts had the idea of composing a music for what he called 'dead tones'. To compose dead tones, he imagined the following procedure: sine tones should be recorded while the tape recorder was in pause position. These sine tones should thus be recorded without any movement at all: even the tape machine should not move. The music would therefore be outside of time (Toop 1979, 387–388). The realization of this composition is technically impossible, since sound is always happening in time: the perception of sound is a result of changing air pressure waves. These pressure waves are movements of air, and movement can only happen when one of the parameters is time.

We hear sound when air pressure waves, created by vibrating material, impact the membranes of our ears. These movements are all essential for the production and reception of sound. It is not possible to create sounding music without any movement, as Goeyvaerts' composition proves, but it is possible to create music without a performer and without musical instruments. Dick Raaijmakers describes a goal of composing in terms of the *generating* approach: 'to produce sounds that are by all means totally independent of any behaviour whatsoever of objects in nature' (Raaijmakers 2007, 435).[21] In the *generating* approach all articulation and timbre that reminds the listener of the seminal source and cause of the sound should be erased. As Stockhausen states:

> In general, one can already recognize a first criterion of quality in an electronic composition in the extent to which it is kept free of all instrumental or other sound associations. Such associations distract the listener's mind from the autonomy of each sound world presented to him, because he is reminded of bells, organs, birds or water-taps. […] Electronic music sounds best only as electronic music, which is to say that it includes as far as possible only sounds and sound relationships that are unique and free of associations, and that make us believe that we have never heard them before. (Stockhausen 2004, 374)

Creating sounds without any association proved to be much more difficult, however, than developing a theory about them. But as was already the case with *reproducing* and *supporting*, the same can be said here: the notional core of the approach is important, not the resulting product itself, which is, in this case, a practical realization of a utopian idea.

Although in electro-acoustic music history Pierre Schaeffer is often seen as the opponent of the ideas of Stockhausen and the Studio für elektronische Musik in Cologne, as concerns his view on musical instruments, he displays a very similar approach to that of Goeyvaerts and Stockhausen. Like these two composers, Schaeffer is also interested in creating a music that exists as pure sound only, without any references to musical instruments or other sound sources. Schaeffer developed his theory during the 1950s and 1960s. As a result of the invention of sound reproduction technologies, almost all sounds became available inside the concert hall. Schaeffer searched for a way to use any sound 'purely for its own sake' as an 'objet sonore', without associations to the source or to the meaning of the sound, as with spoken language (Schaeffer 2005, 65). He found a solution by cutting sounds into very short fragments. He cut the recorded sound at any point where a break in energy output occurred, a technique he termed 'stress-articulation'. The cause and meaning of the original sound should become, in this way, unrecognizable. Recorded sounds originally produced by, for example, cars, an orchestra, a bird, or a human voice are all brought to the same level of objet sonore in this way. Compiling these different sounds into more extensive formations creates what Schaeffer calls 'objets musicales', which then form the main elements of a composition.

The *generating* approach regards sound as the only component of music. Furthermore, the sounds that Goeyvaerts, Stockhausen and Schaeffer composed needed to be devoid of reference to the cause of the sound: semantic acts of sound creation should not be present in this music. A significant contrast in the music created in this manner, compared with that accomplished by the *reproducing* and *supporting* approach, is that in this case there is no sound at all without a loudspeaker. The music does not exist until the sound leaves the loudspeaker, contrary to the *reproducing* and *supporting* approach, in which case the music already exists before it leaves the loudspeakers, even before it enters the microphone. What is probably the most significant difference between these two first approaches and the *generating* approach is that for the first time in history, music was heard without the use of a musical instrument. Only the sound radiated by the loudspeaker came into existence, and what shaped the electrical signal that drove the loudspeaker became irrelevant. Whether it was air pressure waves caused by a physical object and picked up by a microphone or an electrical signal shaped by an electric circuitry is unimportant, since the semantic acts of sound creation should not be recognizable in this music.[22]

Interacting: Resonance and resistance

An object is identified as an instrument according to the recognizability of the interactions between performer and instrument, which result in musical sound. As soon as these interactions are no longer perceivable, a music without musical instruments can be generated. The opposite can probably also be contended: as soon as we perceive musical interactions between a performer and an object, we will perceive this object as a musical instrument. This *interacting* between performer and object is the fourth approach towards microphones and loudspeakers.

Regarding the relationship between players and conventional musical instruments, a musical instrument, as with all other instruments, is often seen as an extension of the human body (Pelinski 2005). The instrument accomplishes a task initiated by the human body. The result of this task is sound to be heard by human beings. This sound comes into being owing to the vibration of a material, which generates air pressure waves. This material vibrates because energy is applied to it, which is largely mechanical energy, applied to the instrument by hitting it, submitting it to air pressure, or through other forms of friction, such as bowing. Often this energy comes from a human body, but it may also be supplied by machines (for example, air pumps in organs) or by nature (the wind in Aeolian harps). It is obvious that this supply of energy is applied with an expected result. The musician hits, blows or strokes the instrument in a specific way, with the expectation of producing a certain sound.

I call this immediate connection between the body of the musician and the body of the instrument the 'resonance' between them. The body of the musician excites the body of the instrument, which will resonate as a result of this excitation. His or her musical ideas become to sound through the body of the instrument. The musician needs the instrument to make the music sound and, at the same time, the instrument cannot sound without the body of the musician. Due to this close connection of both bodies, musicians often appear to be one with their instrument. Their musical ideas, what is happening in their minds, seem to be immediately expressed by the instrument.

This immediate connection between musician and musical instrument, as if the instrument is obeying all the wishes of the musician, is of course an illusion. During a performance, the instrument might be perceived as being an extension of the body of the performer, but this is the result of an elaborate process. The performer has been communicating with the instrument for a long while – commonly called practicing the instrument – and has therefore learned how the instrument reacts to his or her actions. Every communication is mediated, since it is a transfer of content from oneself to another. And even prior to any expression, the idea has already been influenced by the instrument on which it will be played. The instrument forms the idea in the mind of the musician. As soon as a musical idea is played on an instrument, one will never be able to hear only the idea without the influence of the musical instrument. The instrument cannot be a neutral mediator, since one cannot subtract the instrument and retain the music. I would therefore say that the relation between musician and instrument is not only characterized by 'resonance' but also by 'resistance': the instrument does not always react to the actions of the musician in the intended way. The impossibility of playing every musical idea on every instrument is in fact an essential characteristic of a musical instrument. It is not endless possibilities but rather the finiteness of these possibilities which render an instrument fruitful for music-making: 'But a musical instrument is no mere means: it does not disappear in its use. The musical instrument remains opaque and one does not know how it will respond to a given gesture' (Evens 2005, 83). Clearly, this position is the antithesis to what was claimed by Riemann, who saw a musical instrument as a mere means for transplanting the ideas of a composer into the heads of the audience.

Whereas playing a glissando on a trombone is relatively easy, a true glissando is impossible to play on the piano. Musical instruments resist the realization of many musical ideas, even when played by a skilled musician. The possibilities of musical instruments have borders, and although these borders may be extendable, they cannot be dissolved completely. The musician often explores these borders: 'The instrument resists the creative impulse, pushes back against the musician, problematising her desire and forcing her to make tactical manoeuvres, right there where the music is happening' (Evens 2005, 162).

The development of most instruments can be seen as a process: the interaction between a musician and an instrument results in either discovering new playing (interacting) techniques or in changing the musical instrument itself. Looking at the three approaches mentioned above – reproducing, supporting and generating – microphones and loudspeakers have not been developed as the result of any form of interaction between them and musicians. For the *reproducing*, *supporting* and *generating* approach, the most desirable feature of microphones and loudspeakers is to display the least resistance possible: they should never be heard creating semantic acts of sound production, not having any resistance at all and be just a transparent device open to all sounds.

Objects that are normally not considered to be musical instruments must be brought by the artist into the realm of musical instruments. Pushing a CD player's play button in the customary way is not regarded as an interaction between performer and musical instrument. But one might imagine a piece of music in which this interaction becomes essential and in that case, the CD player would become a musical instrument. Imagine a piece of music in which the performer is not only pushing the play button of the CD player on and off but is also choosing different tracks and using the fast forward button. And we do not have to only imagine this, since there are plenty of examples that demonstrate the use of a CD player and CDs as musical instruments, such as *Music for Two CD Players* (1986) by Yasunao Tone.[23] Using these kinds of musical interactions, objects can be transformed into musical instruments. The necessary treatment in order for these objects to be perceived as instruments would be to interact with them in such a way that results in music. It is in this way that all kinds of non-musical instrument objects (turntables, radios, laptops, spoons, bikes and wine glasses) can be transformed into musical instruments. Although built to transmit the vibrations produced by other objects, microphones and loudspeakers are naturally made from physical material themselves. To discover their qualities as musical instruments, one needs to force them to make their own material perceptible and discover the resonance and resistance that arise when interacting with this material. The sound *should* be shaped by the physical presence of the microphones and loudspeakers themselves. Microphones and loudspeakers *should* take over the semantic aspect of the sound production instead of remaining as transparent as possible. By treating these devices as instruments, new aspects of music can be discovered. The division between the musician as creating sound on a musical instrument and loudspeaker as a passive device that reproduces this sound is not accurate for this approach; instead, musician, microphone and loudspeaker can start a complex relationship in which sounds are created from characteristics of the devices themselves.

Notes

1 For an investigation of definitions of musical instruments, see the article *What is instrumentality in new digital musical devices? A contribution from cognitive linguistics and psychology* by Cance, Genevois, and Dubois (2009). This article reveals that many definitions of musical instruments are tautologies: for example, 'an object or device for producing musical sounds', quoting the *New Oxford American Dictionary* of 2007 (Cance, Genevois, and Dubois 2009, n.p.), or seen as impossible: for example, as phrased by André Schaeffner, 'Can we define the term musical instrument? It is impossible, as well as we cannot state any precise definition of music that would be valid in every situation, every period, and every use of this art.' Quoted from *Origine des instruments de musique. Introduction ethnologique à l'histoire de la musique instrumentale* (Schaeffner 1968, 9) in (Cance, Genevois, and Dubois 2009, n.p.).

2 The human voice is often regarded as an exception among musical instruments, since it has not been purpose-built. In the twentieth century, it became common though to refer to the human voice as a musical instrument. It is, for example, the first instrument discussed in *Instrumentation in der Musik des 20. Jahrhunderts* (Gieseler, Lombardi, and Weyer 1985).

3 Overviews of patents of sound reproduction technology can be found online: Ehlert (2004) and Ubu Web (2011).

4 Margaret Kartomi gives a good overview of instrument classifications as well as outlining the influence of the Hornbostel and Sachs system on many classification systems (Kartomi 1990).

5 I will not go into detail concerning questions such as what might be the musical work, the role of the score, or the performance of the score, since this would lead me too far away from my subject. Much has been written about this, for example in *Zu einer Theorie der musikalischen Reproduktion: Aufzeichnungen, ein Entwurf und zwei Schemata*. (Adorno 2005) and in *The Imaginary Museum of Musical Works: An Essay in the Philosophy of Music.* (Goehr 2007).

6 A classical example is the question up for discussion: whether or not the laptop or computer is a musical instrument (Evens 2005, 130).

7 Think, for example, of the mixing board-only performances by Marko Ciciliani, turntable artists like Christian Marclay, radio pieces like Joanna Bailie's *On and Off 2*, sirens in the compositions of Edgard Varèse, the virtuoso spoon performances by Tran Quang Hai, the singing bicycles used by Godfried Willem Raes in his second symphony, and the use of wine glasses in compositions by George Crumb.

8 For an account of the history of the idea of high fidelity, see Chapter 5 'The Social Genesis of Sound Fidelity' in Sterne (2003, 215–286).

9 This became the new name for the Victor Talking Machine Company after they were bought by RCA (Radio Corporation of America).

10 This article also mentions that a minority does consider the radio to be a musical instrument. The article is concluded with the remark that 'the radio may rise to the dignity accorded the saxophone and the jew's-harp' (Anonymous 1930, 344). The author of this article still has hope that one day the radio will develop into a musical instrument.

11 Some books that cover this subject are: *Noise: The Political Economy of Music* (Attali 1985), *Repeated Takes: A Short History of Recording and Its Effects on Music* (Chanan 1995), *Klang (ohne) Körper: Spuren und Potenziale des Körpers in der Elektronischen Musik* (Harenberg and Weissberg 2010b), *Capturing Sound: How Technology Has Changed Music* (Katz 2004) and *The Audible Past: Cultural Origins of Sound Reproduction* (Sterne 2003).

12 Turntable techniques are related to acoustic laws: for example the so-called scratching that is achieved by moving the record back and forth. The faster the record is played, the higher and shorter this sound is.

13 It should be mentioned here explicitly that Boehmer postulates the terza prattica as playing a completely new aesthetic and social role. Use of electricity is thus not the only criteria resulting in a piece of music being part of the terza prattica (Boehmer 2004, 165).

14 The prima prattica, also called stile antico, is a musical practice centering around vocal polyphony with strict counterpoint. The more monodic style, using more regular rhythms as well as more (so-called) vertical harmonies is seconda prattica, also called stile moderno. The change from prima to seconda prattica during the seventeenth century has been seen as a very important shift of paradigms in music.

15 The term 'speaking-cabinet' as well as 'sound-cabinet' is used by Galpin in this article as a synonym for 'loud-speaker'.

16 Correctly speaking, the piano converts the performer's energy input into a sonic output, since a piano cannot produce any energy by itself.

17 Paul Hindemith wrote a handful of pieces especially for the gramophone in 1930, but these initiatives never became more than experiments (Katz 2004, 99–112).

18 My translation of 'niet-instrument-gebonden klankorganisator'.

19 The vibrations of tuning forks come quite close to producing a sine wave, as I will demonstrate in the next chapter.

20 'Met dode tonen' is Dutch for 'with dead tones'. *Compositie nr. 4 met dode tonen* is an unrealized score of electronic music (Cross 1968, 53), since the idea is technically not realizable. During the 1970s, Goeyvaerts realized a modified version of this piece in the IPEM studio in Ghent, subsequently recorded on compact disc (D'Action 2008).

21 My translation of 'geluiden maken die uiteraard volledig los staan van welke gedragingen van objecten in de natuur dan ook' (Raaijmakers 2007, 435).

22 The *generating* approach includes many different ways of producing sound. It is out of the scope of my research to mention the different possibilities of sound production, but I would like to make one important differentiation. Electronic sounds can be generated and processed (whether their starting point is as air waves picked up by microphones or as electrical signals) in an analogue or in a digital form. The main difference between these two is that analogue synthesis still needs a specific 'instrument' or 'device' to produce a certain sound, whereas in digital technology there is no specific material set-up needed anymore. A computer can generate all kind of sounds, while using the same bytes (Weissberg 2010, 174).

23 See Straebel (2009, 25–28) and Kelly (2009, 210–283) for a general overview on compositions for CDs and CD players.

3

The Sound of Microphones and Loudspeakers

Acoustic feedback: An electromechanical oscillator

What happens when the music in front of the microphone and coming out of the loudspeaker is taken away, so that only the sounds found between microphone and loudspeaker remain? I wish to discover what kind of sound can be produced by microphone and loudspeaker in themselves, with the least possible influence from sounds derived from conventional musical instruments or signal processing. This investigation brings me back to the beginning of the nineteenth century, where I examine several ideas and devices which have played a role in the development of sound reproduction technology, as well as electric musical instruments developed during the nineteenth and the beginning of the twentieth century.

The microphone is a silent device, not producing sound but picking up vibrations with its diaphragm. It is designed to respond to any mechanical vibrations, mostly transferred as air pressure waves, and as long as these sounds are within the limits of its capabilities to respond, the microphone is able to transduce them into an electrical signal.

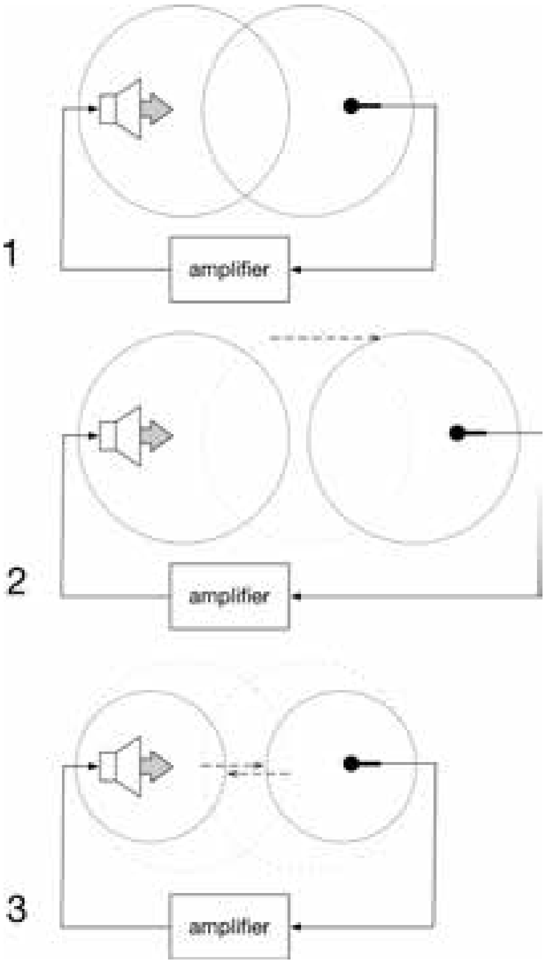
The loudspeaker is a sounding device. It produces sound through the movements of its diaphragm, which are triggered by the electrical signal received by the loudspeaker. The loudspeaker itself has no way to verify if this electrical current is meant to be turned into sound or not. It merely moves its diaphragm analogue to the current, within the range of its material possibilities. Like the microphone, the loudspeaker diaphragm vibrates according to the limits of its frequency and amplitude range.

The loudspeaker needs an alternating electrical current to produce vibrations which form air pressure waves, perceived by humans as sound. It can use the electric current produced by a microphone. Since the electric current of a microphone is very small, this current must be increased by an amplifier for it to become functional for the loudspeaker.[1] At the same time, the microphone could pick up the air pressure waves emitted by this loudspeaker. The microphone output would be emitted by the loudspeaker again. If the sound is now softer than the first time, the sound will pretty soon disappear. But if the sound is emitted on a higher level that what is commonly called ‘ acoustic feedback’ is generated. The amplitude of the sound waves will become higher and higher, till the system will start to oscillate on one or several frequencies. Every element of a microphone and loudspeaker set-up has its own resonance frequencies. The entire system of microphone, amplifier and loudspeaker vibrates at the frequency which is produced with the least resistance. Depending on their material characteristics, as well as the characteristics of all the other parts of the system, the diaphragms will vibrate more easily at certain frequencies than at others. This is the so-called resonance frequency of the system.[2] The system oscillates at this frequency, oscillating repetitively and regularly between its two extreme values. The several parts will pick-up or diffuse the signal with slightly more amplitude at this frequency. Every time the signal is diffused and picked up again, the resonance frequencies get even more energy. For this reason, when the microphone and loudspeaker are placed close to each other, or high volumes are used, the resonance frequency will become louder and louder in the sound and thus cause acoustic feedback. The phenomenon takes place as soon as there is enough overlap contact between the sound waves diffused by a loudspeaker and picked up by a microphone. This contact is achieved when microphone and loudspeaker are placed (too) close to each other or through high enough amplification levels.[3] By producing acoustic feedback, microphones and loudspeakers become audible (Scheme 3.1). Konrad Boehmer* explains that the conjoined nature of sound-production and sound-diffusion is typical for musical instruments:

> The unity of sound-production and sound-diffusion which is so typical of instruments, was disrupted in favour of another scheme, namely that of sound recording and sound fixation. Here the diffusion became a separate act, in which the composition was no longer realized in sound but was already realized when made to sound. (Boehmer 2004, 161)

I prefer to call sound-production sound-shaping due to the difference between the actual physical sound source – which is still the loudspeaker – and the semantic act of sound creation, the result of which is what is heard through the loudspeaker. Some of the construction elements of a musical instrument might be mainly designed for shaping the sound (like the strings of the violin) and others for amplifying the sound (like the body of the violin). The vibration of the strings cannot exist without them emitting any sound (the sound would be much softer if it would not be connected to the wooden body), and the wooden body cannot amplify the sound of the strings without shaping this sound according to its own characteristics.

In music heard through loudspeakers, sound-shaping and sound-diffusion are divided into two different processes and should influence each other as little as possible, in contrast to how these processes are connected to each other in musical instruments. The signals that cause the movements of the diaphragms of microphones and loudspeakers could be termed the sound-shaping process, whether caused by air pressure waves, in case of microphones, or an electrical signal, as is the case for loudspeakers. This sound-shaping is mostly done in one of two ways: either a sound source (such as a musical instrument) generates air pressure waves which bring the microphone diaphragm into vibration (as is the case with the *reproducing* and *supporting* approach), or loudspeaker diaphragm is brought into vibration by an electrical signal which has been shaped by an electric circuit (this is typical for the *generating* approach).



Scheme 3.1
Microphone and loudspeaker set-ups.
(1) This microphone and loudspeaker set-up causes acoustic feedback.
(2) Feedback can be avoided by increasing the distance between microphone and loudspeaker.
(3) Feedback can be avoided by decreasing the volume of microphone and/or loudspeaker.

Often the resulting loudspeaker diaphragm movements are a combination of these two possibilities, as when a sound has been recorded and processed by a computer before it is sent to a loudspeaker. The resulting sound-diffusions are performed by the actual diaphragm movements of the loudspeaker. The form of the air pressure waves produced by these diaphragm movements should be influenced as little as possible by the material and construction of the diaphragm.

In an acoustic feedback set-up the material characteristics of microphones and loudspeakers influence the sonic result to a great deal, similar as the material of conventional instruments is highly influential on the resulting sound. When a microphone and loudspeaker set-up produces acoustic feedback, it is behaving as a musical instrument in this unification of sound-shaping and sound-diffusion. No sound is coming from outside of the set-up,[4] as is normally the case when a microphone picks up a sound like a singing voice, and all sound radiated by the loudspeaker is shaped by the set-up of microphone, amplifier and loudspeaker.

Robert Ashley* states that acoustic feedback is the only sound intrinsic to electronic music (Holmes 2008, 185). This implies that the sound produced by the combination of microphone, amplifier and loudspeaker – without any noticeable additional sound sources – is the fundamental sound of electronic music. In acoustic feedback both sound-shaping and sound-diffusion are accomplished by the microphone, amplifier and loudspeaker set-up, unique for this set-up, since it commonly has an input sound or electrical signal. It is probably for this reason that Ashley thinks of acoustic feedback as intrinsic to electronic music, in the same way as one could think of the intrinsic sound of the violin. When the violin is played, all parts of the violin together form a single sound system, interacting with each other to produce sound. But for the violin, there is no other possibility to produce another sound than its own, whereas for microphones and loudspeakers it is an abnormality.

There is a second reason, however, why acoustic feedback might be called the intrinsic sound of electronic music. In electronic music, oscillators are often used to generate an electrical signal. An oscillator is in that case a circuit which generates, like the acoustic feedback system, a repetitive signal, for instance in the form of a sine, a sawtooth or a square wave. For this reason acoustic feedback could be compared to an electronic oscillator. The sound of oscillators is often immediately identified as a typical electronic sound, since perfectly regular oscillating vibrations, for example sine and square waves, are not found in mechanical vibrations causing sound. Oscillators are used in all kind of electronic warning signals, such as the beeps used for signalling the pushing of a knob on phones, microwaves and in elevators. When electricity is the supplier of the energy needed to create the audio signal, as is the case with electronic oscillators and with acoustic feedback, there is no human movement involved, and it is therefore possible to keep the energy supply absolutely stable. Therefore the output signal of electronic oscillators will be regular, without any deviation. Acoustic feedback behaves largely like an electronic oscillator, although the process is slightly different. The electrical energy supply might be constant, but acoustic feedback includes a mechanical aspect as well, namely what takes place from loudspeaker diaphragm to the point when microphone movement vibrations are transduced back to electricity again. For this reason, acoustic feedback is an electromechanical oscillator. As I will explore in more detail in the next two chapters, it is exactly this connection between the electronic processing and the laws of classical mechanics which can be very fruitful for all manners of exploration in the *interaction* approach.

As soon as sound reproduction technology was introduced at the end of the nineteenth century, the phenomenon of acoustic feedback came into being as well.

This generative sound of the machines themselves was regarded as completely undesirable. A good example is the disturbance of telephone conversations at the beginning of the twentieth century by acoustic feedback. The telephone needed to be convincing to the public as a suitable new device for the transportation of music or conversations, and naturally any other sound was disturbing. Since a telephone microphone and loudspeaker are very close to each other, often both placed in the telephone horn, it was not easy to prevent the microphone from picking up sounds from the loudspeaker as well, instead of only the acoustic source, a voice, for example, that it was supposed to transport. Acoustic feedback could easily occur, and it was immediately identified as an annoying by-product which should be avoided. As can be read in patents at the beginning of the twentieth century, telephone conversations were indeed often disturbed by this so-called 'howling' (Patent Gilchrest 1906).

Not surprisingly, scientific research on amplifying audio signals has concerned itself with avoiding feedback. Already as early as 1911, research on acoustic feedback was being performed by Søren Absalon Larsen, and the French term for acoustic feedback 'effet Larsen' is named after him. Paul Boner* was one of the first to carry out extensive research on feedback, and in the 1960s proposed solutions for avoiding feedback, by, for example, introducing equalization in public address systems (Boner and Boner 1966). With the use of equalizers, which reduce or increase certain frequencies in the audio signal, acoustic feedback could be avoided during concerts that use an amplification system, by searching for the resonance frequencies and filtering them out with the result that resonance on these frequencies would become impossible.

The tuning fork: An early sine wave generator

Thinking of an acoustic feedback system as an oscillator capable of producing vibrations circulating through the system of microphone, amplifier and loudspeaker is not only theoretically correct but has also been put into practice. An example is the tuning fork oscillator or resonator, a combination of a tuning fork and two small electromagnets, each placed close to one of the tuning fork prongs, often used in all kind of precision equipment, such as radiotechnology, in the middle of the twentieth century. In the first RCA Electronic Music Synthesizer from 1955, called Mark I, twelve tuning fork oscillators were used to produce sine waves on the twelve pitches of a chromatic scale (Holmes 2008, 195; Manning 2004, 88). Normally the sound of a struck tuning fork dies away fairly quickly owing to the resistance of its material. In this oscillator, the loss of energy is avoided by amplifying and feeding the vibrations of the tuning fork back into one of the prongs. One coil picks up the vibrations of one of the prongs of the fork, generating a current in the coil at the same frequency as these vibrations, which is then amplified and fed back into the other coil, causing it to vibrate. Since both prongs are physically connected to each other, they will always vibrate with the same frequency and amplitude, but in opposite directions (Cary 1992, 339–340).

At first sight, a tuning fork seems not at all related to microphones and loudspeakers. But, taking a closer look at the two small electromagnets and the prongs of the tuning fork, it might become clear that the prongs of this small metal object can be compared with the loudspeaker and microphone in an acoustic feedback set-up. The transduction of the vibrations of the diaphragms of many microphones and loudspeakers is often performed by electromagnets. The two small electromagnets close to the prongs function similarly to the electromagnetic coil construction in a dynamic microphone, or to the electromagnetic voice coil in a loudspeaker: one picks up the vibrations of the prong (this prong could therefore be seen as equivalent to a microphone diaphragm), and the other brings the second prong into vibration (and this prong thus becomes equivalent to the loudspeaker diaphragm).

Contrary to the acoustic feedback described previously, here it is not air which transports the sound waves but the metal of the tuning fork. The fragile and light diaphragms of loudspeaker and microphone have solidified into rigid and solid bars of metal. The independence of loudspeaker and microphone becomes dissolved in the tuning fork, whose prongs are connected to each other. The tuning fork oscillator could be seen as an acoustic feedback set-up in which microphone and loudspeaker have lost their flexibility of vibrating on (ideally) every possible frequency and are only able to respond to a single frequency. The resonance frequency of this system is determined by the frequency of the tuning fork. This oscillator demonstrates well that the element of a feedback system that has the strongest resonance for a certain frequency will cause the rest of the system also to vibrate at this frequency. Owing to the high resistance of the tuning fork to vibrate at any frequency other than its own resonance frequency, the frequency of the tuning fork becomes the resonance frequency of the whole system of tuning fork, coils and amplifier. Whereas the coils could also easily contain a current with a different frequency, it is impossible to get a tuning fork to vibrate at another resonance frequency than its own.

The tuning fork is connected in more ways than this to the development of microphones and loudspeakers. The tuning fork was an important scientific instrument to the nineteenth-century acoustician. Invented in 1711 by the trumpeter John Shore, the tuning fork, with its quality of fixed pitch, was meant first and foremost as a practical help in tuning instruments.[5] The material properties of the tuning fork remain stable even under temperature changes, making it an extremely suitable device for delivering a reference pitch for tuning. Owing to its form, the two prongs vibrate in opposite directions, causing the stem to move up and down in the motion of a sine wave. For this reason, the tuning fork produces that what is often called a 'pure' tone, a tone which is probably as close as one can get to a sine wave without using any electrical or electronic means. Hence its use in the early Mark I synthesizer as a sine wave oscillator. Only the attack produces other audible partials, but these fade out rapidly owing to the great resistance of the tuning fork against these frequencies, and as soon as electromagnets are used to cause the vibrations no attack will be heard.

Although the tuning fork was invented as an aid to tuning musical instruments, scientists discovered the usefulness of its characteristics, especially the periodic vibrations causing a pure tone, as described above, and started to make use of it for their research on sound. It became a crucial instrument in nineteenth-century acoustical research, and several tuning fork experiments are closely related to the development of loudspeaker and microphone technology. Especially in musical applications, the relationship between microphones and loudspeakers in nineteenth-century scientific experiments with early devices was often not unidirectional, with a signal flow moving only from microphone to loudspeaker as is the case in the *reproducing* and *supporting* approach. The connection in nineteenth-century devices and instruments is often more related to a feedback situation: the sonic output is connected again to the input. These devices often used the *sound-shaping* possibilities of the microphone and loudspeaker set-up, contrary to later developments, during the first third of the twentieth century with their high fidelity aesthetic and the corresponding demand for a transparent mediation of sound.

Transforming sound into a researchable object

An important endeavour of acoustical science in the nineteenth century was to gain a more empirical knowledge of the world through the execution of experiments and to objectify this knowledge by deriving it in ways which tried to be as independent as possible from individual perception (Rieger 2006, 9). Science itself became increasingly professionalized, developing stricter research methods and requirements. The experiments I discuss belong to the stream of research which attempted to objectify knowledge on sound and listening.[6]

One of the main problems with acoustical research is that sound is time-bound, consisting as it does of an alternation of low and high air pressure. For this reason it was impossible for nineteenth-century scientists to make analytical observations on sound itself, since a longer period of time is needed to observe and analyse a phenomenon and sound could only be researched the moment it was heard. What scientists needed was an object which did not change over time and thus could be studied. Scientists began to look for ways to transform sound into researchable objects, to convert sound waves into forms more amenable to analysis. A second aim of acoustic research in the nineteenth century, investigated by controlling the different partials of a sound, was to understand the phenomenon of sound colour, in other words the spectral characteristics of a sound. This endeavour led ultimately to electronic sound synthesis in the twentieth century.

At the beginning of the nineteenth century, Thomas Young* describes in his *A Course of Lectures* (1807) a machine by means of which sound may be directly notated, consisting of a cylinder, covered with paper or wax, which rotates at a certain speed. By connecting a pencil to a rapidly vibrating (and therefore sounding) object and placing the tip of this pencil in contact with paper on a rotating cylinder, the markings left by the pencil will notate and visualize the vibrations of the object (Young 1845, 288–289).[7] Young reports that up to 1000 vibrations per second may thus be measured (Young 1845, 146–147).[8] With this experiment, he was searching for a direct transcription of sound into a visual representation, a typical nineteenth-century endeavour to objectify the perception of a specific phenomenon (in this case sound). The vibrations of the object, normally only perceivable as sound, were visualized by this method into a graphical result, becoming an object suitable for research instead of a vanishing sound. A tuning fork was, as might be expected, an interesting sound source to notate, with its simple and clear periodic vibration, very similar to a sine wave.[9] The experimental machine described and developed by Young was soon used and refined by different scientists such as Wilhelm Weber, Wilhelm Wertheim and Jean-Marie Constant Duhamel to notate the vibrations of a tuning fork (Jackson 2012, 203). This method to notate sound waves emitted by an object was often called the graphical method (Figure 3.1). There is no material yet for sound mediation, such as the diaphragm will become, but the vibrations of the object are immediately written down.

Hermann von Helmholtz: Tuning fork experiments

One of the most notable scientists in the nineteenth century, performing a wide range of research on acoustics, was Hermann von Helmholtz*. What is remarkable in his research is the use of acoustic knowledge to clarify music. This was not only a new scientific approach in the nineteenth century but also revolutionized music theory. His approach to music as a physical phenomenon and his aim of objectifying phenomena

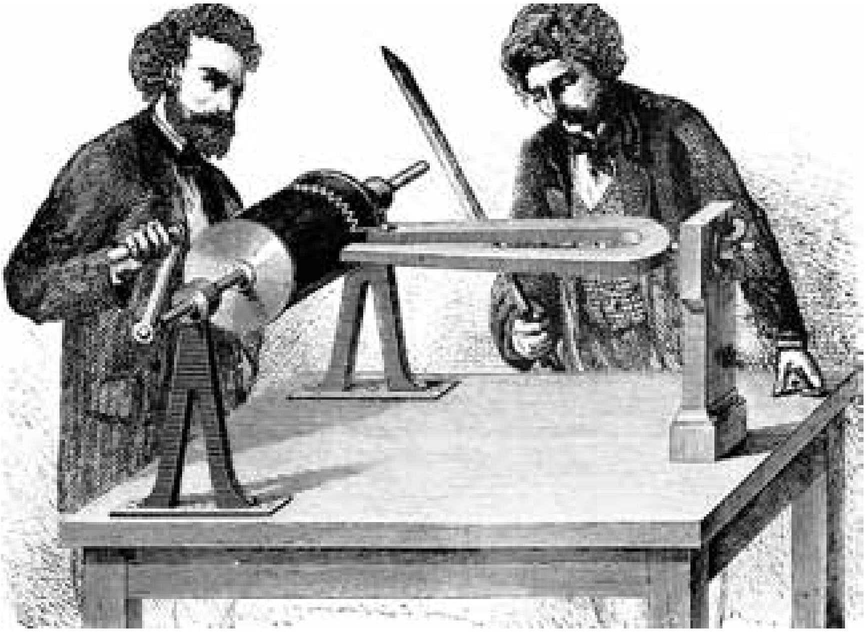


Figure 3.1 Graphical method of observing the mode of vibration of a tuning fork (Lockyer 1878, 167). The tuning fork seems to be too large to be brought in vibration by the small bow. This picture is probably meant for explaining the principle and not a realistic picture of how the experiment was executed.

such as sound, the sense of hearing, and consonance brought about a rethinking of most of the axioms of music theory.[10] Helmholtz was familiar with the method of notating the vibrations of a tuning fork, which he describes in much detail in his famous book on the immediate relationship and effect of acoustics on music theory: *On the Sensations of Tone as a Physiological Basis for the Theory of Music* (*Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* 1863). The graphical method ('eine grafische Methode') is well-known around this time and Helmholtz describes it as being used by mathematicians and physicists for facilitating the study of sound waves (Helmholtz 1863, 33).

More noteworthy, however, is his description of how one can visually create a moving, albeit limited, reproduction of the wave the tuning fork has notated:

> If the reader wishes to reproduce the motion of the vibrating point, he has only to cut a narrow vertical slit in a piece of paper, and place it over fig. 6 or fig. 7 [pictures of waveforms notated with the graphical method, CvE], so as to show a very small portion of the curve through the vertical slit, and draw the book slowly but uniformly under the slit, from right to left; the white or black point in the slit will then appear to move backwards and forwards in precisely the same manner as the original drawing point attached to the fork, only of course much more slowly. (Helmholtz 1895, 21)[11]

Helmholtz thus not only visualizes a static image of the movement of the prongs of the tuning fork, he also brings the graphical and immovable representation back into motion. By moving the transcription of the vibration underneath a paper with a small slit, only one representation of location in time of the prong can be seen. Helmholtz foreshadows here, in a very abstract manner, the reproducibility of tuning fork vibrations. Exactly this idea, that sound is nothing more than reproducible vibrations, becomes very important for several developments in sound technology during the succeeding decades. This is one of the first indications of the possibility of reversing the transformation of audible sound waves into a fixed form. It is clear, though, that Helmholtz was not interested in reproducing the sound itself, but in reproducing the movement of the object causing the sound. This is typical for thinking about sounding objects in what could be called the age before the membrane: there is no physical object yet that transduces these sound waves from one form of energy or storage to another. This changes as soon as a membrane, in microphones and loudspeaker often called diaphragm, is introduced.

One of the subsequent experiments which Helmholtz describes in this book is the phenomenon of Mittönen (English: literally, to co-sound, translated as sympathetic resonance by Alexander Ellis* in his translation of *Die Lehre von den Tonempfindungen* [Helmholtz 1895, 40]). This word, uncommon in modern German usage, refers to the phenomenon of an object starting to vibrate in response to the vibrations made by another object, which is placed close to, but not touching, this object. An experiment for demonstrating this phenomenon was often performed using the favourite instrument of the nineteenth century acoustician: two tuning forks of the same frequency, placed close to each other, each mounted on its own resonant box (to amplify it). If one of the two tuning forks was struck and subsequently quickly dampened, the second tuning fork could be heard resonating owing to the sympathetic vibrations caused by air pressure waves from the struck tuning fork (Helmholtz 1863, 67–68).

This is again a very common nineteenth-century experiment and proved that sound waves are transmitted through air. Objects capable of resonating at the frequencies of these sound waves will do so, if the sound waves are strong enough. The tuning fork is used as a kind of 'pre-microphonic' object: not only is a tuning fork able to transform sound waves, as proven by the first experiment, it is also capable of responding to vibrations transported through the air. Scientists started to look for an object able to *co-sound* with as many frequencies as possible. This is a characteristic which would become a premise for microphone diaphragms. This would be useful, as it would become possible to notate sounds without attaching a pencil directly to the sounding object. One of the disadvantages of the pencil was that it could only be attached to sounding objects with a very specific shape. It was impossible, for example, to notate the wave signal of the human voice or of most musical instruments. The solution was to use a thin membrane, able to vibrate at many different frequencies, instead of objects like tuning forks, with only one resonating frequency. All kinds of sounds transported by air pressure waves could be picked up by this membrane and notated, without any physical contact with the vibrating object.

An early example of using a membrane to pick up the vibrations of a sound source is the phonautograph (patented in 1857 by Édouard-Léon Scott de Martinville*), which uses two small, thin membranes, analogous to the tympanic membrane of the ear. Scott developed this machine by copying the physical properties of the human ear, and it was able to notate sound waves on smoked paper by means of a stylus attached to the membranes (Sterne 2003, 32–36). These notations were called phonautograms. Not surprisingly, one of the first sounds notated by Scott was actually the sound of a tuning fork, which, with its simple sound wave, was suitable for demonstrating the reliable functioning of the machine. This machine is a unidirectional, linear system: all manner of sounds can be notated with the phonautograph, but no part of it can be brought back into movement and heard again.[12]

Hermann von Helmholtz: Tuning forks reproduce human vowels

Scott's phonautograph enabled a more objective study of sound by registering it as a static form outside of its perceptual immediacy in time. Helmholtz found a solution for the second aim of nineteenth-century acoustic research, namely to analyse the different partials of a harmonic spectrum[13] separately, by developing a device to research vowels as produced by human voices: *Apparat zur künstlichen Zusammensetzung der Vocalklänge* (Helmholtz 1863, v) (Figure 3.2).[14] Based on Fourier's theorem, which stated that every wave can be analysed as a sum of sine waves, he sought to reproduce human vowels by combining several partials, a process which would subsequently be called additive synthesis. Helmholtz described in *Die Lehre von den Tonempfindungen* a device using eight tuning forks of different pitch for the several partials of the spectrum,[15] kept in constant vibration with the aid of electromagnets.

These tuning forks function in nearly the same way as the tuning fork oscillator described above, except that instead of a feedback circuit keeping the oscillator in motion, all eight tuning fork oscillators are kept in motion by an intermittent current, provided by the largest tuning fork *G* (see Figure 3.2). Through the regular movements of the prongs of this large tuning fork, a connection to galvanic batteries *z* (very small next to *F*) is opened and closed, resulting in switching the current flow through the tuning forks on and off. Owing to this intermittent current, the electromagnets of each of the eight tuning forks (*R1-R8*) also become magnetized, attracting the tuning fork when the current flow is on and demagnetizing when the current flow is off, allowing the prongs of the tuning forks to return to their original positions. If the electric current is turned on and off by tuning fork *G* in a frequency that forms a division of the frequency of the tuning forks *R1-R8*, these tuning forks will start to vibrate at their own frequency. Since all tuning fork harmonic frequencies in this device are related to each other as partial tones (with relations such as 1:2:3:4:5), their harmonic frequencies can be divided by one fundamental frequency, which is the frequency which was chosen for the largest tuning fork *G*. One of the prongs of tuning fork *G* is connected to a small metal wire c, which is dipped into a small vessel filled with mercury at *N*. Through this connection an electric current (follow the arrows in the drawing), delivered by galvanic batteries *z*, is travelling through the mercury and the prong of the tuning fork, to both electromagnets *E*. Electromagnets get magnetized as soon as a current is flowing through them, so both electromagnets will now attract the prongs of the tuning fork. This movement of the tuning fork prong will cause the wire *c*, attached to the prong, to be taken out of the mercury and thus breaking the electric circuit. Consequently there is no magnetic attraction, and the tuning fork returns to its initial state. This generates a current again, with a connection of the wires on the prongs to the mercury again. Since a tuning fork only vibrates at one frequency, the making and breaking of the electric circuit always occurs at the frequency of the tuning fork. In this way,

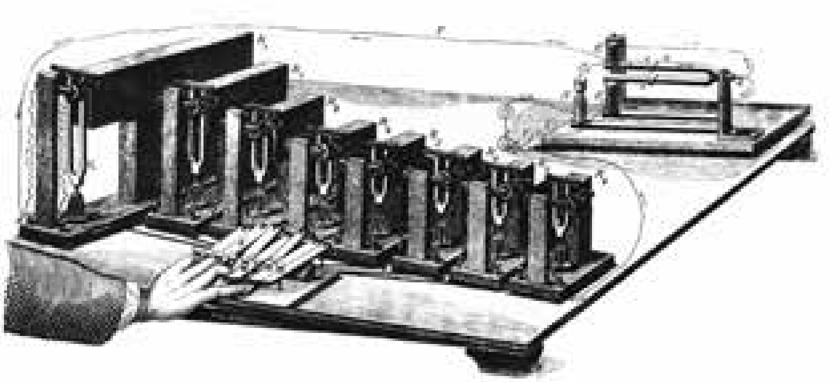


Figure 3.2 *Apparat zur künstlichen Zusammensetzung der Vocalklänge* as developed by Herrmann von Helmholtz (Pisko 1865, 22).

Helmholtz achieves a constant vibration of the tuning fork, which will keep the other eight tuning forks *R1* till *R8* vibrating as well. To make these eight tuning forks audible, he attached resonant tubes (placed right behind the tuning forks *R1* till *R8*) that could be opened and closed. Normally tuning forks were attached to resonant boxes to make them audible, but since Helmholtz wanted to be able to hear them separately and in different combinations, he decided to attach adjustable resonators in the form of these tubes, their lengths adapted to the frequency of the tuning fork they were placed on. Different combinations of tuning forks can be sounding with help of the keyboard *K* to open the resonator of each fork separately. The volume of the tuning fork sounds could be modified by opening or closing the resonator, being able to compose the spectrum of a sound, similar to what became interesting for composers working with electronic sound in the 1950s, but not yet regarded at all as a compositional method in the late nineteenth century. But scientists were fascinated by these long sounds, which could be hold as long as the batteries lasted, and soon musical instrument builders would be interested in them as well. Nowadays these inventions by Helmholtz and his contemporaries are often inspiring for composers again. Jan-Peter E.R. Sonntag* rebuilt the Apparat bei Helmholtz with more tuning forks and larger resonators. This synthesizer avant la lettre, called *sonH-Vowel-Synth*, plays an important role in his opera *Sinus* (2015). The recent popularity of tuning forks in sound art and composition reveals once more how technical progression and art works are not necessarily related to each other. Now that it is seemingly possible to produce every sound you can imagine through a loudspeaker, the physical aspect of sound production, especially by combining mechanical and electrical possibilities becomes appealing again. Simon Løffler* composed *H* (2016) for four performers and sixteen tuning forks, during which each performer is playing a kind of four fork version of Helmholtz's *Apparat*. Nicolas Bernier* has been making several installations on the works of Helmholtz, such as *frequencies (a/friction)* (2015) which combines a sine wave oscillator with a tuning fork.

The *Apparat zur künstlichen Zusammensetzung der Vocalklänge* combines the functions of sound-shaping and sound-diffusion. The vibrations are caused by the electromagnets, and the eight tuning forks and their connected cardboard tubes perform both functions. Similar to the prongs of the tuning fork used in an electromechanical oscillator, the prongs in this device could be seen as the predecessors of the diaphragm of a loudspeaker. If they were flattened out into light and thin membranes, able to resonate at several frequencies instead of just one, like the membrane in Scott's phonautograph, the tuning fork would function as a loudspeaker diaphragm. Such tuning fork applications during the nineteenth century began an evolution towards the applications of membranes performing similar functions.

The tympanic principle and the tuning fork principle

The tuning fork experiments are different if not opposed to the general use of membranes in sound reproduction technologies, a principle called 'tympanic' by Jonathan Sterne. The tympanic principle is derived from the structure of the ear, which contains a membrane able to transmit all kinds of different sounds from the external world to our inner ear. As Sterne writes, '[…] the functioning of the tympanic membrane (also known as the diaphragm or the eardrum) in the human ear was the model for the diaphragms in all subsequent sound-reproduction technologies. As a result, I call the mechanical principle behind transducers *tympanic*' (Sterne 2003, 22). This principle is the result of looking for a neutral transformation of sound into another medium, in which the visual representation of sound should be transferred directly from the vibrating object to the materials for notation, as Young demonstrated by attaching a stylus to the object. To represent visually the waveform of all sounds human beings hear, it would be simplest to attach a pencil to the membrane of the ear and transfer these vibrations directly to paper. Therefore, it might not come as a surprise that Alexander Graham Bell and Clarence Blake performed exactly this experiment. An extensive exploration of their work on the ear-phonautograph can be found in *The Audible Past* (Sterne 2003, 31–35). The tympanic principle – used, for example, by Scott in his phonautograph as mentioned above – is the result of a human-based model of sound perception. The object used for transmission in the tympanic principle, the membrane, should disappear, and no hint of it should be recognizable. We are not able to hear our own ear hearing, and the same should be the case for sound reproduction technology.

I would like to introduce the tuning fork principle, as a concept to set against Sterne's tympanic principle. This principle approaches the process from the opposite direction, since it reproduces only one frequency instead of many. Contrary to the tympanic principle, it is therefore not a generalization for sound reproduction, but a specification. Their sound is the result of the resonating qualities of their shape: a small, strong and regular shape tends to resonate at a single frequency or multiples of this single frequency. String instruments are good examples of this principle. Since they are not as stiff as a tuning fork, they will have more partials, but their resonance is in multiples of the fundamental. Membranes in musical instruments such as drums tend to sound noisy, without a clear pitch. They are resonating at many different frequencies, similar to the diaphragms of microphones and loudspeakers or our ear's membrane. The tuning fork method arises from an abstract approach to sound and music, with the so-called pure tone, one sole frequency, named the sine wave, as its starting point. Even if I must underline that the tuning fork itself does not produce a sine wave, but produces a wave that is as close to a sine wave as nineteenth-century scientists could obtain. This wave is seen as the source of all musical sound, since every sound wave can (theoretically) be constructed by adding multiple sine waves, each of a different frequency. According to this principle, the object used for transmission of sound (the tuning fork) is clearly connected with the sounds being produced, and the object is audible, in contrast to the membrane in the tympanic principle, which should not be audible at all. The difference between these approaches may be found in the semantic act of sound creation: the membrane in the tympanic principle transmits all kinds of acts of sound creation – except its own sound – whereas the tuning fork can only transmit one act of sound creation, namely its own sound. The physical and semantic acts of sound creation are always identical in the tuning fork principle.

In my view, these two different principles complement one another, and both form the starting points of two different directions taken in sound technology, especially as concerns microphones and loudspeakers. This is the beginning of a division between one principle that focuses on a transparent reproduction of all possible sounds, using an imperceptible tool, and another which focuses on the converse, that is to say on producing a musical sound using a perceptible tool. When considering the development of sound reproduction technology during the nineteenth century, many of the new devices used tuning forks for either picking up frequencies (with the help of sympathetic resonance) or to emit frequencies (with the help of electromagnets). These tuning forks were gradually replaced at the end of the nineteenth century by membranes, which took over the function of picking up frequencies (microphones) and emitting them (loudspeakers).

Alexander Bell: Metal rods reproduce sound

The tuning fork device developed by Helmholtz was encountered in 1866 by Alexander Graham Bell. He misunderstood the description of this device, however, and thought it was a device for transmitting spoken vowels to the tuning forks (Gorman 1994, n.p.). For this reason, Bell became convinced that it should be possible to transmit not only vowels, but all manner of sounds, through a wire by means of electricity. He thus evidently confused sound synthesis with sound reproduction, but his confusion also demonstrates how close these two ways of sound production can be. It is because of this confusion and because of Bell's fascination for sympathetic resonance that he developed the idea of creating a new device for transmitting vocal sounds. By singing into the piano, while pressing down the sustaining pedal, Bell noticed that sound was produced due to the sympathetic resonance of the piano strings. The resonance of the piano strings is of course a very crude reproduction of the voice, but it gave Bell the idea that, if a piano contained more strings within one octave, it would be able to reproduce a sonic image of the sung sound (Bell 1878, 19). The strings of the piano could be compared with the eight tuning forks in Helmholtz's device, since every string is responsible for one partial of the spectrum.[16] By using many more than the eight tuning forks, employed by Helmholtz for reproducing vocal sounds, Bell expected to be able to reproduce sounds of higher quality and representational accuracy. Since using tuning forks would be expensive and impractical, Bell thought of using metal rods. He imagined such a device in 1874 and called it a *harp apparatus* (see Figure 3.3). He describes the functioning of this apparatus as follows:

> Utter a sound in the neighbourhood of the harp H, and certain of the rods would be thrown into vibration with different amplitudes. At the other end of the circuit the corresponding rods of the other harp H' would vibrate with their proper relations of force, and the timbre of the sound would be reproduced. (Bell 1878, 19)

This harp apparatus is a hybrid device between a musical instrument and a sound reproduction device. The sound (re)produced is no longer entirely shaped and emitted by the instrument itself, as would be the case with a conventional musical instrument. The tuning forks are still faintly present in the form of the many rods, but all of them

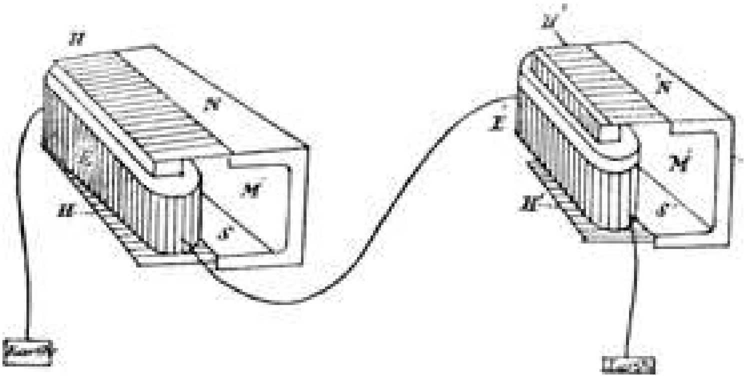


Figure 3.3 Harp apparatus (Bell 1878, 19). Bell intended with this design, that as soon as the rods H are brought into vibration by a sound, the electromagnet E outputs an intermittent current which will be transmitted to the other electromagnet E'. The rods H' should then be brought into vibration by electromagnet E'.

together perform the function of microphone (the first harp) and loudspeaker (the second harp). They are audibly functioning, transmitting a sound, yet the semantic act of sound creation is generated by something besides the rods themselves.[17] The border between the sound of the object itself and the sound of this object reproduced by another object is crossed with this apparatus, so that two different acts of sound creation may simultaneously be heard, one of them being a strongly modified reproduction of the sound produced in front of one of the harps (a semantic act of sound creation) and the other being the sound of the rods themselves (a physical act of sound creation). The original sound is transformed by the resonance characteristics of the rods themselves and is therefore literally heard as a sounding through the rods. The harp apparatus was never developed by Bell and would probably not have functioned anyway,[18] but an impression of how a voice might be transmitted through many rods, in this case the strings of a piano, may be found in the piece *A Letter from Schoenberg* (1996) by Peter Ablinger*. For this piece, each of the different partials of the sound of a reading voice is assigned to one of the 88 keys of a piano by a computer. During the performance, the piano 'reads' a letter by Arnold Schoenberg. When listening to the sound of this composition on the piano, what is heard is a complex and rapidly changing sound of many piano keys played together in groups or rapidly after each other. However, as soon as one reads the text while listening to the virtuoso piano music, the sound of the piano can be recognized as being a reproduction of the spoken text. This piece reveals the fragility of the border between perceiving abstract musical sounds, shaped and emitted by one and the same instrument (namely the piano), and sounds that are shaped by one object (in this case the human voice) and emitted by another (the piano). In this paradigm, the piano is situated between the *tuning fork principle* and the *tympanic principle*. The acts of sound creation within the piano result in two kinds of perception. First of all, the physical acts of sound creation are recognized as being done by the piano, and the piano functions as a musical instrument. But, when reading the text while listening to the piano sounds, the resulting sound is recognized as referring to semantic acts of sound creation different from the sound of the piano itself, namely a human voice talking. The piano could in this piece be identified as a sound reproduction device instead of a musical instrument.

Alexander Bell: Metal plates reproduce sound

Bell began to search for a less complicated way of transmitting sounds, without the need for an endless amount of rods, inspired by the book *Wonders of Electricity* by Jean Baptiste Alexandre Baille, in which an acoustic telegraph is mentioned (Baille 1872, 140–143). What Baille describes could be called a flattened tuning fork, namely a steel plate. Bell exchanged the tuning forks in Helmholtz's device with such plates, and discovered that the combination of a metal plate and an electromagnet could reproduce not only a single pitch but other partials of the spectrum too (Gorman 1994, n.p.). With this discovery, Bell realized that a single plate was able to transmit a complex sound, containing several frequencies, eliminating the need for the many rods of the harp.

Bell's concept of transmitting sound evolved gradually from the tuning fork principle towards the tympanic principle. The many strings of the piano, the many tuning forks and rods of the harp, all resonating in response to a single frequency, are exchanged for a single membrane, able to vibrate, ideally, in response to all audible frequencies. Both the piano strings and the metal rods will be able to react also to frequencies that are related to their partials, since their spectrum contains more than a single frequency contrary to the spectrum of a tuning fork. The resonance will in general be the largest on the fundamental frequency and only the first two or three partials might resonate as well, so the number of resonance frequencies is still very limited compared to a membrane. How this sound reproduction would function is illustrated well by Figure 3.4, once again a representation of a device which was never realized in this form. The elements for transmitting and receiving the sound waves of these two devices are designed by Bell to be exactly symmetrical. This reveals the paradigm of reproducing exactly the same sound as that which has been picked up. These symmetrical drawings seem to reinforce the following idea: if the receiver, in fact a kind of microphone, vibrates in a certain way and the transmitter, in fact a kind of loudspeaker, vibrates in exactly the same way, the sound is reproduced perfectly. The ideal microphone and loudspeakers for Bell vibrate in exact symmetry, copying the movements of the prongs of a tuning fork, which also vibrate symmetrically in opposition. It is no surprise that his first drawings of the telephone depict a same kind of symmetry (Figure 3.5). Listening seems to be the reverse act of talking.

Looking at the construction of microphones and loudspeakers nowadays, it is clear that Bell's idea of symmetry was not the ideal technical implementation: although based on a similar principle, modern microphones often display a completely different construction than loudspeakers do, and tend to have, for example, much smaller diaphragms than

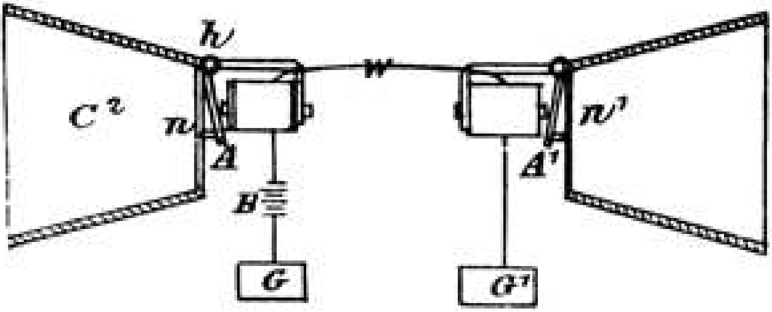


Figure 3.4 Design of two identical devices for transforming sound into electricity that use single metal plates instead of many rods (Bell 1878, 22).

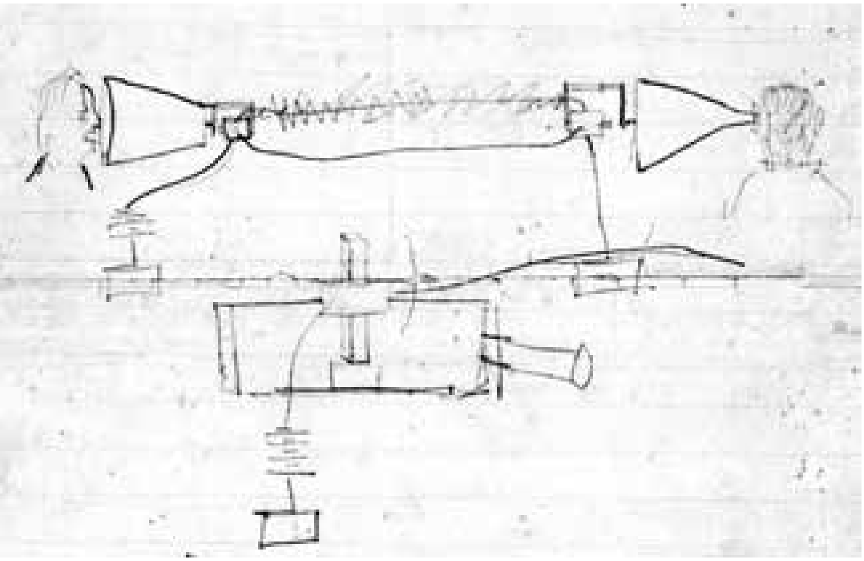


Figure 3.5 In early sketches of a telephone conversation mouth- and earpiece are nearly identical. Drawing by Alexander Graham Bell, 1876. Alexander Graham Bell Collection, Alexander Graham Bell family papers, 1834–1974, Library of Congress.

loudspeakers. Picking up air pressure waves and emitting them are functions which require a different construction for optimal performance, even when the same kind of transducing technology is used. Microphone diaphragms must vibrate in response to air pressure waves and should thus be very sensitive and light, reacting easily to every small fluctuation in the air pressure waves caused by sound sources in the space. Loudspeaker diaphragms, on the other hand, need to be able to produce air pressure waves, and their diaphragm should therefore react as minimally as possible to any other air pressure waves, emitted from other sound sources in the space. For this reason, early telephones as well as phonographs use two different diaphragms for the recording and the reproducing of sound, which can be seen in Thomas Edison's* phonograph patent (Edison 1878). When using the 'perfected' phonograph – as this device was called by Edison – which is known for recording and reproducing sound through the same horn, there are nonetheless two different diaphragms for these functions. That microphones and loudspeakers are indeed mirrors of each other as suggested by Bell is demonstrated though by the frequent use of microphones as loudspeakers or loudspeakers as microphones in the less hi-fi-sound-oriented scene of experimental music. Nicolas Collins* describes some of these possibilities in the chapter 'In/Out: Speaker as Microphone, Microphone as Speaker–The Symmetry of it All' (Collins 2009, 19–21). Obviously the reproduction qualities of these kinds of reversed technologies do not conform to the ideals demanded by the *reproducing* approach, but might be very fruitful for artistic explorations (see for example the performance by Lara Stanic, described in Chapter 5).

Richard Eisenmann: An electric piano with tuning forks

The evolution from metal rods to metal plates is one of many stages in Bell's – and other's – development of an early telephone.[19] The telephone is a tympanic device: the sound should be transmitted and not shaped by the device, since one wants to hear what the person at the other side of the line is saying. This sound reproduction technology was developed through the process of transforming the tuning fork principle into a tympanic one. The same process may be observed in the development of musical instruments which use electrical means for sound production, for example the electric piano between the 1880s and 1930s, beginning with the *elektrophonisches Klavier* invented by Richard Eisenmann*. His intention was to develop a new sound for grand pianos with the aid of electricity (Buß 1892, 92). The starting point this time is not scientific research, as was the case with the tuning fork experiments by Young and Helmholtz, but a musical instrument, namely the grand piano. The main element is a modified tuning fork current interrupter, a similar device as built around tuning fork *G* in Helmholtz's Apparat. Eisenmann used tuning forks and electromagnets to keep the strings of a piano sounding, or even to increase the sound level after the strings have been struck, which of course is impossible with an acoustical piano (Figure 3.6). In 1866, he patented an electromagnetic system for grand pianos and upright pianos which would prolong individual tones as well as generate sounds in imitation of other instruments (Eisenmann 1887). His patent description, as well as the various drawings, describes implementing a tuning fork-based current interrupter for every string of the piano which is intended to be kept in vibration.

This strong similarity to Helmholtz's tuning fork device is hardly astonishing since Eisenmann was working for Helmholtz at the institute for physics at the University of Berlin. Briefly, Eisenmann's piano works as follows: a tuning fork is placed next to a

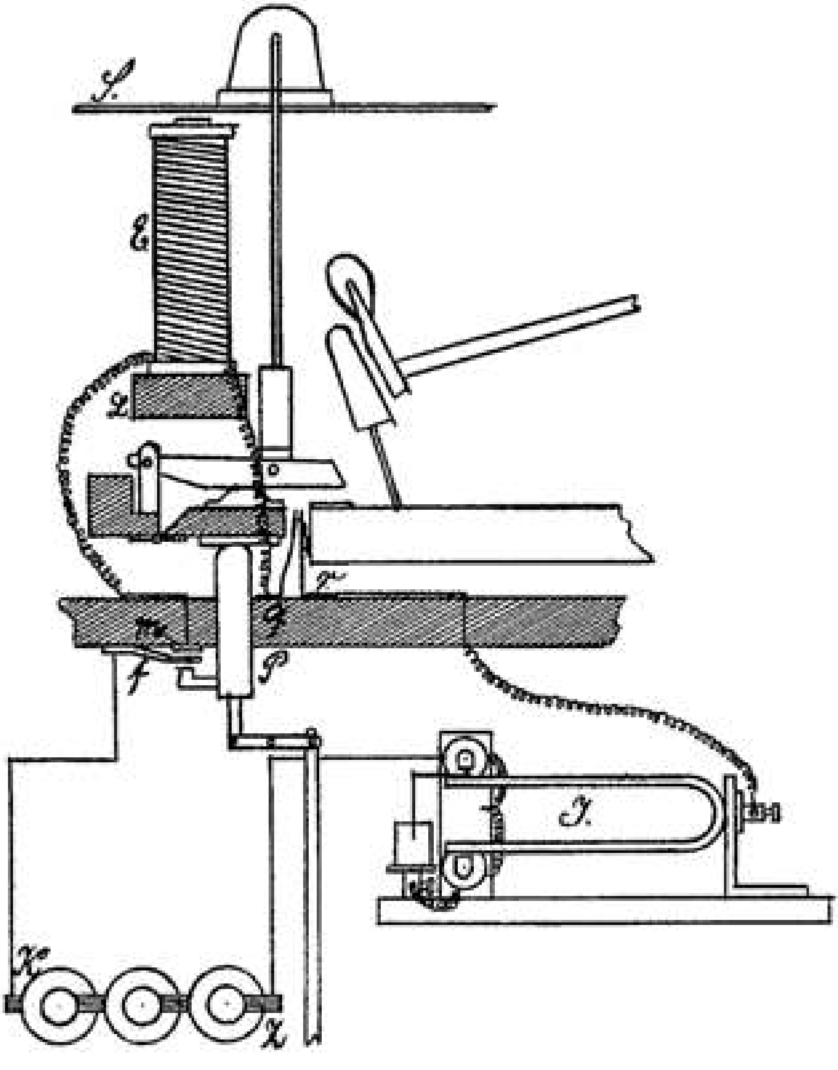


Figure 3.6 Eisenmann use a similar tuning fork interrupter for his electric piano as Helmholtz did in his *Apparat* (Eisenmann 1887, 3).

piano string with the same pitch. As soon as a key of the piano is struck, bringing the associated piano string into vibration by means of its attached hammer, the tuning fork will start to vibrate sympathetically along with the string. With the help of a tuning fork current interrupter, an intermittent current is produced, which is sent to an electromagnet placed close to the corresponding string. Instead of keeping the tuning fork in vibration, as in Helmholtz's device, the piano string is kept in vibration by the electromagnets. Eisenmann introduces a feedback loop here, since the tuning fork will resonate in sympathy with the piano string again, and in this way everything is kept in motion. By means of a pedal, the current may be disconnected, so that the piano string stops vibrating.

The actual sounding results of this electrophonic piano are reviewed very positively in a contemporary magazine, which mentions that the piano can sound now similar to a violoncello, an organ or even an Aeolian harp (Buß 1892, 93), but I doubt that this new technology functioned very well at the time.[20] As described as well in this article, Eisenmann soon patented a second version of the piano, but this time using a microphone. Similar to Bell, he replaced the tuning fork, which was able to respond through sympathetic vibration to a single frequency, with a device that ideally can pick up all frequencies. The microphone was still in a very early stage when Bell developed his telephone, but by the beginning of the 1890s when Eisenmann patented his second electric piano using a device that used a diaphragm for picking up frequencies and converted them in electric current had become quite common. The development of the microphone was a long and complex process, in which many people were involved and many different devices and systems were patented and built. A good impression of how many different attempts and inventions were done is displayed by, for example, Théodose Du Moncel in his book *Le téléphone, le microphone et le phonographe* (Du Moncel 1878). In this book, published already in 1878, just two years after Bell patented his telephone, du Moncel compares many early microphones of the 1870s, of whom the best known nowadays are by David Edward Hughes*. In Eisenmann's patent the microphone seems to be already a known device to him, and Eisenmann's description of what a microphone is able to do is very optimistic: 'It is known that a microphone reproduces exactly all sounds which are produced in its neighborhood. It reproduces a whole opera, the voices of the singers and the sounds of each instrument' (Eisenmann 1893, 3). That the microphone surely did not solve all the problems for Eisenmann's electric piano becomes obvious, when one realizes that the first electric piano functioning well enough to be commercially available was eventually developed only in the 1930s.

George Dieckmann: A piano string oscillator

One of the possibilities (next to the more common ones of using tuning forks or microphones) George F. Dieckmann proposes to achieve an electrical-driven piano is to use the piano string itself to function as its own current interrupter (Figure 3.7). The vibrations of the piano string are used to open and close the connection to the current flow sent to the electromagnets, which attract the piano string, so it keeps vibrating. These electromagnets are placed above the string, so every time the current is going through the electromagnets, they pull the string upwards (without touching the string). The connection between the small contact-spring *M* and the piano string is disconnected by this upwards movement of the string. This causes

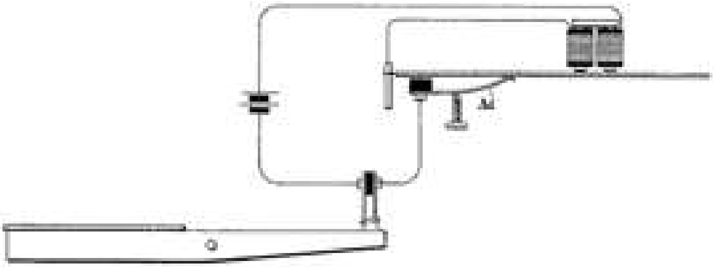


Figure 3.7 The piano string serves as its own current interrupter. When the string vibrates the connection between string and contact-spring M is opened and closed (Dieckmann 1887, 3).

the current to be interrupted and the electromagnets to be demagnetized. The piano string falls down again, the connection with the contact-spring *M* is closed, and the current circuit as well, causing the electromagnets to attract the string again (Dieckmann 1887, 3).

There is no division between sound-shaping and sound-diffusion, since the strings of the piano fulfil both functions, emitting sound similarly to the diaphragm of a loudspeaker while simultaneously functioning similarly to the diaphragm of a microphone by transducing the string vibration to the electromagnets.[21] There is no tympanic component, and the electrical component of the musical instrument is integrated into the instrument itself. No membrane is needed to pick up or generate air pressure waves, since the piano strings themselves pick up mechanical vibrations as well as generate them. Sound production in this electric piano thus works entirely according to the tuning fork principle, a technique which would soon become atypical in the production of musical sound with the help of electricity.

What makes this Dieckmann patent very elegant is the complete integration of the electric technology in the mechanical part of the piano. But unfortunately it is very difficult to convert this elegant idea into a well-functioning solution. Besides the fragility of the construction of the current interrupter with the help of the piano string, the small contact-spring is touching the piano string every time the circuit is closed, which is evidently influencing the sound of the piano. This kind of distortion of the sound was judged negatively by Dieckmann himself, but nearly eighty years later a composer used a similar set-up to create wild, new sounds. Although probably not knowing the Dieckmann piano, David Behrman* composed *Wave Train* (1966). In this piece, electric guitar pick-ups (a kind of electromagnets) take over the function of the small contact springs for picking up the vibrations of the piano strings. They are placed loosely on the piano strings. Their signal is amplified through big loudspeakers, placed underneath the piano. As Behrman demands in the score:

> Arrange amplifier gains so that a very powerful (loud) feedback develops when the volume control is raised to near maximum. The strings' pitches under the pickups should have an effect on the feedback pitches. The loudspeaker feedback should make the strings resonate, and this resonance should, in turn, be fed back into the speakers through the pickups. (Behrman 2011, 111)

Due to the vibrations in the piano strings created by the guitar amplifiers the guitar pick-ups on top of the strings will start to jump (Collins 2010, 42). The distortion effect of the small contact-spring in Dieckmanns piano is enlarged here by the jumping pickups and its unpredictability is one of the main qualities of the composition, instead of what was regarded as a technical failure eighty years earlier.

Bechstein-Siemens-Nernst-piano: Piano, radio and gramophone through the same loudspeaker

The availability of better-quality loudspeakers in the 1920s was soon reflected in new developments involving electric pianos. A good example is the Bechstein-Siemens-Nernst-piano in 1931, better known under the name 'Neo Bechstein'.[22] All three contributors to its development and name were experts on different terrains: the Bechstein company had experience in building excellent pianos since 1853, the Siemens company had patented one of the first loudspeakers in 1874, and Hermann Walther Nernst was a professor at the same institute of physics at the University of Berlin where Helmholtz and Eisenmann had conducted their research.[23] The Neo Bechstein piano differs from the Eisenmann- and Dieckmann-instruments in being simply amplified rather than using a complicated feedback and current interrupter system. The strings are placed close to several electromagnets (one per five strings), which this time are used not to maintain the vibration of the strings, as in the Eisenmann- and Dieckmann-pianos, but as microphones, converting the vibrations of the steel strings into electrical signals which are transmitted to a large loudspeaker, whereas the acoustic sound of the piano was made to be as soft as possible, using a special construction with very small hammers and without a soundboard.

Sound production by this instrument is based on the tympanic principle, and microphones and loudspeakers are integrated according to the *supporting* approach. The electromagnets pick up the vibrations of the strings, these are amplified by an amplifier, and a loudspeaker emits this sound. There is no longer a connection through sound waves between loudspeaker and microphone, creating an acoustic feedback circuit, and the mechanics of the piano are no longer involved in a direct exchange with the electrical sound production, as was the case with the electric pianos previously discussed. The piano strings are nothing more than the suppliers of sound vibrations to a loudspeaker diaphragm, therefore shaping, but not emitting the sound, which should only be emitted by means of the loudspeaker. Contrary to the Eisenmann- and Dieckmann-pianos, there is thus a clear division between the musical instrument and the loudspeaker, which is treated as a device whose purpose is to make a certain sound audible, without revealing a characteristic sound of its own. As mentioned by Fritz Winckel, who collaborated on the development of the Neo Bechstein (Figure 3.8), the quality of loudspeakers needed to be good enough for them to function as a transparent sound emitter (Winckel 1931, 843).

The tympanic function of the loudspeaker used for the Neo Bechstein is underlined by the combination of the *supporting* and *reproducing* approach within this single instrument. Not only is the instrument amplified by the loudspeaker, but the *reproducing* approach is integrated into the instrument itself through the addition of a radio receiver as well as a connection to a gramophone to play records (Bechstein 1932, 19). One of the main reasons for these additions was, according to Bechstein, to bring the practice of music-making back into the living room, as in the nineteenth century, when people were still playing violin or piano in the living room, instead of having everything played from record. The musical instruments depicted on the advertisement 'To the Wife' in Klamath Falls have been united now in one single instrument. With this instrument, one could combine passively listening to music with actively playing the music itself, which, in Bechsteins opinion, offered a deeper insight in the music. As he describes the use of this home entertainment system: 'Now one can

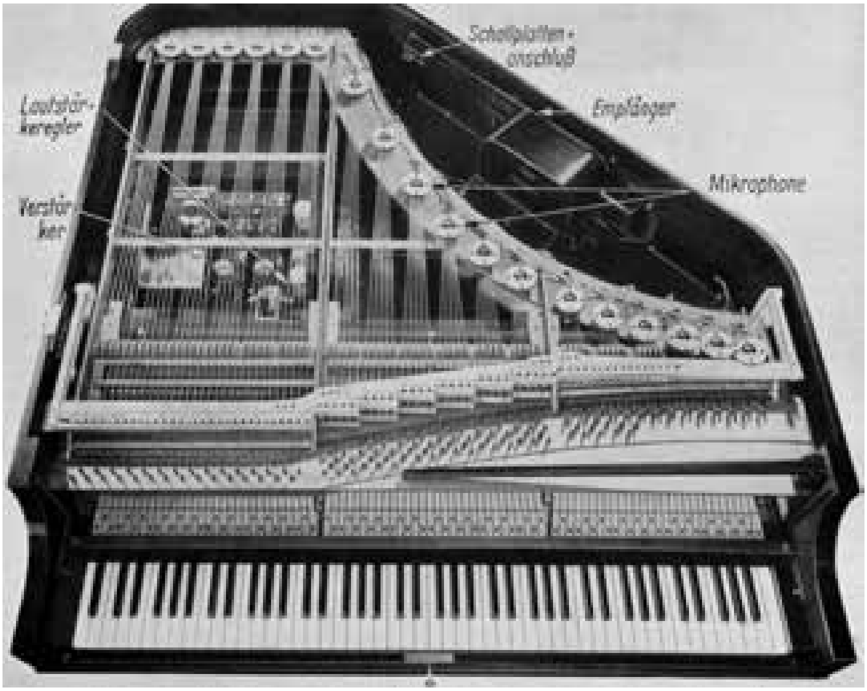


Figure 3.8 The core elements of the Neo Bechstein: an amplifier (*Verstärker*), a volume slider (*Lautstärkeregler*), a connection for a gramophone (*Schallplattenanschluß*), a radio (*Empfänger*) and electro-magnets (*Mikrophone*) (Winckel 1931, 840).

play for hours, day or night, without disturbing the neighbours: listening in between to the latest news, or allowing Lamond [a contemporary pianist, CvE] to play a sonata by Beethoven, and then immediately try to imitate him; each time the same sound is produced in the same way' (Bechstein 1932, 20).[24]

This connection of musical instrument, radio and gramophone to the same device for sound-diffusion, namely the loudspeaker, reveals that the latter is thought of not as contributing any characteristic sound of its own but as a device able to reproduce all kinds of sounds. As Bechstein claims in the citation mentioned above, the sound of the piano through the radio or the gramophone is the same sound as that of the piano: 'each time the same sound is produced in the same way' (Bechstein 1932, 20). The sound caused by the vibrations of the piano strings is conceptualized in exactly the same way as the sound of a piano recording. All music-making in the home, whether a recording, a radio show or a piece played on the piano, sounds through one single sound-diffusion device: the loudspeaker.

The developments described above constitute only one of the possible focuses on the development of the first microphones and loudspeakers during the nineteenth century, one that focus mainly on the development of musical instruments. Tuning forks, with their relatively heavy solid metal prongs, and microphones and loudspeakers with their thin and light diaphragms seem to fulfil completely different functions. These two extremes were very close to each other in the nineteenth century, often being used to perform the same function in scientific devices or musical instruments. Tuning forks were often replaced by microphones and loudspeakers in later versions of similar devices or applications. With the Neo Bechstein, a stage was reached in microphone and loudspeaker development in which microphones and loudspeakers functioned sufficiently well enough to be used for different approaches at the same time (*reproducing* and *supporting*).

The tuning fork principle also developed in another direction, and this resulted in the *generating* approach. Helmholtz *Apparat zur künstlichen Zusammensetzung der Vocalklänge* could be seen as an early synthesizer. Pieces like Goeyvaerts' *Compositie Nummer 5 met zuivere tonen* [Dutch for *with pure tones*] as well as Stockhausen's *Studie II*, both using only sine waves for additive synthesis could be seen as direct descendants of the idea of developing sounds by adding the partials of a frequency spectrum. Since there is a clear division in these pieces between the device shaping the sound (sine wave generators) and that diffusing the sound (loudspeakers), the *generating* approach could also be said to implement the tympanic principle for the diffusion of its sounds. The devices discussed in this chapter which used the tuning fork principle could therefore be regarded as predecessors of sine tone generators, as well as of microphones and loudspeakers.

Notes

1 As I described in Chapter 2, the invention of electric amplification has been very important for the mainstream use of microphones and loudspeakers in all kind of applications.

2 In fact, most vibrating objects have resonance frequencies, at which they tend to vibrate much easier, than at other frequencies. A well-known example is the glass that breaks when brought into vibration at its resonance frequency and a more dangerous resonance frequency can be found in the vibrations of bridges, which can break when they are brought in their resonance frequency.

3 This system does not only contain microphone, amplifier and loudspeaker, but of course all components in between those elements as well. An acoustic feedback system is also shaped by the distance between microphone and loudspeaker, the acoustics of the space, air humidity, as well as the cables used to transport the electric current from one component of the set-up to another.

4 There is of course a small input excitation needed to bring the microphone diaphragm into vibration. This can be caused by a soft noise created by the amplifier or by some background noise in the room. Nonetheless the impression is that the sounds come into being 'out of nowhere'.

5 For a history of the tuning fork and its role in nineteenth century science, see *Die Geschichte der Stimmgabel – Teil 1: Die Erfindung der Stimmgabel, ihr Weg in der Musik und den Naturwissenschaften* (Feldmann 2008) and *From Scientific Instruments to Musical Instruments: The Tuning Fork, the Metronome, and the Siren* (Jackson 2012, 202–205).

6 The relationship between music and science in the nineteenth century is explored in-depth in *Harmonious Triads: Physicists, Musicians, and Instrument Makers in Nineteenth-Century Germany* (Jackson 2006).

7 Of course, the vibrations of the sounding object have to be strong enough to bring the pencil into motion and, correspondingly, the pencil has to be light enough to transfer the vibrations of the sounding objects with the least possible distortion.

8 This is a tone with a frequency of 1000 hertz (the term for vibrations per second).

9 It might be the case, as is mentioned in several sources, that Thomas Young also used a tuning fork as a sounding object; however, I have not found a mention of this in his *Lectures*.

10 The book *Helmholtz Musicus: Die Objektivierung der Musik im 19. Jahrhundert durch Helmholtz's Lehre von den Tonempfindungen* (Rieger 2006) gives an elaborated investigation into the influence of the work of Helmholtz on music theory.

11 This quotation is from the translation by Alexander Ellis. The original German version by Helmholtz is:

> Will der Leser die Bewegung des schwingenden Punktes sich reproduzieren, so schneide er sich in ein Blatt Papier einen senkrechten schmalen Schlitz, lege das Papier über Fig. 6 oder 7, so daß er durch den senkrechten Schlitz einen kleinen Teil der Kurve sieht, und ziehe nun das Buch unter dem Papier langsam fort, so wird der weiße oder schwarze Punkt in dem Schlitz gerade so hin- und hergehen, nur langsamer, als es ursprünglich die Gabel getan hat.
>
> (Helmholtz 1863, 35)

12 In 2008, a sonic reproduction of the air pressure waves as notated in these phonautograms was achieved by digitalizing the notated wave forms (Giovannoni et al. 2008).

13 A harmonic spectrum is a spectrum which partials are all whole number multiples of the fundamental frequency.

14 The translation is device for the artificial formation of vocal sounds.

15 In the Koenig Catalogue, the pitches are described as: ut2, ut3, sol3, ut4, mi4, sol4, ut5. One pitch is thus missing here, since Koenig describes eight tuning fork oscillators (Koenig 1865, 10). I assume the harmonic spectrum was used, in which case si-bemol4 would be missing. Pitches would be c2, c3, g3, c4, e4, g4, b-flat4 and c5.

16 A main difference between the piano and the device by Helmholtz is the many partials of a harmonic spectrum produced by a piano string as opposed to the single frequency produced by tuning forks.

17 I have clarified, what I mean with the semantic act of sound creation in Chapter 2.

18 The harp apparatus would not have functioned, because an amplification between the ‘microphone’ (the first harp H) and the ‘loudspeaker’ (the second harp H”) is missing. The electrical signal is therefore too small to bring the rods of harp H” in audible vibrations.

19 The history of the invention of the telephone is actually much more complicated than the small steps I detail here and definitely should not be assigned to Bell alone. Names like Philipp Reis, Elisha Gray and Antonio Meucci should be mentioned, especially how the ideas about transporting sound ‘travelled’ between these people and how patents and money played an important role as well. Since this is not part of my research and extensive literature on this subject has already been written, I will not write more about this. A very early account on the complexity of this subject can be found in *Le téléphone, le microphone et le phonographe* (Du Moncel 1878), More recent examples are the books *The Telephone and Its Several Inventors: a History* (Coe 1995), *The Telephone Patent Conspiracy of 1876: The Elisha Gray-Alexander Bell Controversy and Its Many Players* (Evenson 2000), Chapter 3 of *Transforming Nature – Ethics, Invention and Discovery* (Gorman 1998).

20 As it seems that only one electric circuit was used and the tuning fork interrupters were therefore all interrupting the same circuit, the result described above seems quite unrealistic. First of all, Helmholtz explains how difficult it is to mount the tuning fork at exactly the right height, so the wire enters and leaves the mercury with every vibration. Secondly, one must use a tuning fork with a low pitch, since the prongs need to make big movements. The prongs of a 120 Hz tuning fork oscillate several millimetres at the end and are therefore suitable for breaking and closing a current circuit through contact with mercury. Higher pitches would not be suitable for implementation in such a system, since the tuning forks would not be able to function as an interrupter. These features make it quite implausible that the piano was really able to sound as differentiated as mentioned above. It seems very unrealistic as well that every string had an electromagnet attached to it and a tuning fork at the same frequency. Most likely the system was implemented on some of the low strings of the piano.

21 Of course the resonant case of the piano influences the final sounding result as well, but this is not important for the feedback process.

22 An in-depth history of the Neo Bechstein can be found in Donhauser (2007).

23 Probably the idea of the Neo Bechstein is still somehow related to the experiments by Eisenmann, performed forty years earlier at the same institution. The swell pedal, especially, which is present in both pianos to create crescendos after the attack, seems to reveal that it is a derivative of the same idea. The ideas of Helmholtz have been of great influence not only on the development of the electric piano but as well on other

electric musical instruments, such as the Telharmonium developed by Thaddeus Cahill in 1897 (Hagen 2010, 60).

24 My translation of: ‘Zoo kan men urenlang spelen op ieder moment van dag of nacht, zonder de buren te storen, intusschen gauw de laatste nieuwsberichten hooren, of zich door Lamond een sonate van Beethoven laten voorspelen, om dan meteen te probeeren, het hem na te doen: steeds ontstaat dezelfde klank op dezelfde wijze’ (Bechstein 1932, 20).

4

Movement, Material and Space: Interacting with Microphones and Loudspeakers

Acoustic feedback: From mistake to music

Acoustic feedback existed from the beginning of the invention of sound reproduction technology using electricity and was regarded as a problem, since it disturbed the *reproducing* and *supporting* approaches, especially the latter, because all amplification systems have a potential to cause feedback. Early telephone systems had also to fight against a 'howling' sound. Feedback became a common feature of much music during the 1960s.[1] The reason that feedback became popular as a means of musical expression might be related to the fact that the acoustic feedback problem was, at that point, largely solved,[2] since the development of amplification technology and the use of filters and other equipment had rendered sound emission much more controllable (Wicke 2001, 247–248). Feedback between loudspeaker and microphone could now be avoided, and there was a clear difference between which sound belonged to the performance and which did not. The sound of acoustic feedback 'entered the spotlight in the 1960s probably due to that decade's character of rebellion and dissent' (Myers 2002, 12) and was regarded as useful material to express this attitude, since is created by purposely misusing the equipment. In some pieces, such as *I feel fine* (1964) by the Beatles, it was used more as an effect or ornamentation. The feedback at the beginning of this song was probably recorded by accident. The Beatles recognized its musical quality and decided to use it in the song.

Apart from these 'effect' appearances, as in the Beatles song, acoustic feedback became fundamental musical material for many artists, such as Jimi Hendrix, David Bowie, Otomo Yoshihide or Sonic Youth. For these artists, feedback functions not merely as a sound symbol but as one of the central sounding elements of the piece. Owing to this musical interaction, misuse becomes a new kind of manipulation. During the performance of such a piece, attention is drawn to the *interaction* between the players and the acoustic feedback system. It is through this 'misuse' that microphone, amplifier and loudspeaker receive and make their own voice audible.

Whereas the uncontrollable aspects of musical instruments were tempered as much as possible in the context of conventional musical instrument development, it was often exactly the unpredictability of sound production with acoustic feedback that made this an interesting music-making tool for many composers and musicians. Moreover, during the 1960s it was an easy and cheap way to create live electronic music, used to advantage by composers such as Robert Ashley* (composing his famous feedback piece

Wolfman[3] in 1964) and David Tudor* (who composed the feedback piece *Microphone*[4] for the 1970 World's Fair in Osaka). Morton Subotnick* mentions using feedback during live performances with piano as early as 1962 (Bernstein and Payne 2008, 126) and Eliane Radigue*, who later produced her principal works utilizing the ARP 2500 synthesizer, relates that she did not have access to a real synthesizer during the 1960s and therefore used acoustic feedback as her principal electronic sound instead. All of these composers regarded the instability and fragility of the feedback system as an interesting element within their compositions. Radigue, for example, describes the sound control process as follows:

> So I worked with electronic sounds, these wild electronic sounds made out of feedback effects from a mic with a loudspeaker. It is very subtle to do that, because you have to find the right distance, just slowly moving it so the sound is slightly changing. You must be very dedicated and precise! (Rodgers 2010, 55)

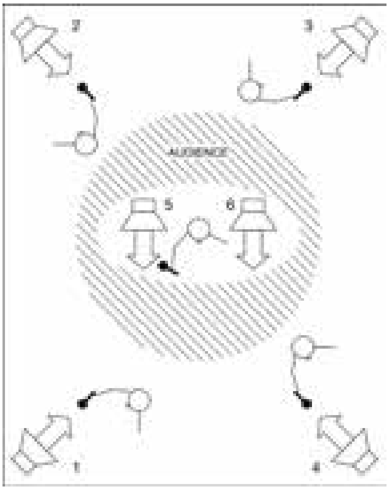
Movement

Quintet ***by Hugh Davies: Changing the distance between microphone and loudspeaker***

One of this early pieces using acoustic feedback as their main sound source is *Quintet* (1968) by Hugh Davies* (Scheme 4.1). The piece is scored for five performers, five microphones and six loudspeakers. The basic musical feature for this piece is the use of acoustic feedback, and each performer has his own acoustic feedback set-up (Davies 1971, 86). Loudspeakers are placed in all four corners of the performance space, and in front of each loudspeaker stands a performer with a microphone in his hand. The fifth performer is placed in the middle, controlling the volumes of all loudspeakers and equipped also with a microphone and two loudspeakers. The performers move their microphones towards the loudspeaker and back, thus changing the distance between microphone and loudspeaker and therefore also the resulting feedback sound.

The score consists of a text with a time line, providing descriptions of what kind of sounds should be heard during a certain time span. The main activity of the four players in front of the loudspeakers is to change the acoustic feedback sounds by moving their microphone forwards and backwards, always with the front of the microphone pointing towards the loudspeaker. In the score, Davies describes the desired sound results as well as how to move the microphone. At 1′45″, for example, the performers should 'move the microphone slowly in different directions, producing increasingly wider pitch intervals' (Davies 1971, 87). At other moments in the piece the performers are instructed to hold steady the last produced sound, make tremolos between close pitches or play arpeggio patterns. Davies indicates three areas of pitch with the letters H, M and L for high, medium and low.

In an acoustic feedback set-up as used in *Quintet*, the microphone picks up air pressure waves which are, for the most part, generated by the vibrations of the



Scheme 4.1 Hugh Davies *Quintet*: the performers modify the acoustic feedback between microphones and loudspeakers by moving the microphone and in this way changing the distance between microphone and loudspeaker.

Note: The schemes of the set-ups in Chapters 4 and 5 are simplified representations of the microphone and loudspeaker set-ups. The number of the channel connected to the loudspeaker is indicated with numbers next to the loudspeaker. Sometimes other electronic equipment is depicted as well, named amplifier, electronics or mixing desk, sometimes these devices are not on the scheme, depending on the importance of their role in the set-up.

loudspeaker diaphragms. To achieve an alteration in these vibrations related solely to an interaction between performer, and microphones and loudspeakers, the distance between microphone and loudspeaker is changed. When the distance between microphone and loudspeaker is increased, the vibrations emitted by the loudspeaker reach the microphone with less energy. But these changes in sound due to changes in distance can in no way be compared with the effect produced when a volume slider is turned down.[5] All manners of alteration in pitch and sound-colour, as well as volume, will occur in such a set-up. The closer the microphone is brought towards the loudspeaker, for example, the higher the pitch of the feedback and the volume of the sound will be, in general. Often, the reaction of an acoustic feedback system is quite unpredictable. An acoustic feedback set-up is an interactive system in which no single parameter can be changed without also bringing about changes in other parameters. This is similar to how conventional musical instruments function: playing a violin string while applying less force will result not only in a smaller amplitude of string vibrations but fewer audible partials as well.

What gives the set-up vitality as an instrument is the very strong interaction between the movements of the performer and feedback sound: every movement with the microphone, even very small ones, changes the sound. The set-up is a 'circle' in which every element influences the next element: from loudspeaker output, to performance space, to microphone input, to (processed) electrical signal sent back to the loudspeaker again. The sound has no recognizable starting point in this set-up, nor does the shaping of the sound have a clear end point. The relationship between performer movements and resulting sounds is much less predictable, though, than is the case with conventional instruments. Whereas the *interaction* relationship is very strong, the resulting sound is often surprising for the audience as well as the performers. Using microphones and loudspeakers to produce feedback is to use them in a way not intended by the manufacturer. These devices, therefore, have an inherent, designed, resistance against this *interacting* approach, which would force them to act to the fullest extent possible as a conventional musical instrument.

Owing to what could be called 'misuse' of microphones and loudspeakers in this piece, the artistic essence is embodied not only in the sounding result but also in the efforts of the performers to obtain it. This means that something that might be regarded as a mistake under other musical circumstances, for example a similar gesture resulting in a differing or unintended sound, is a vital element of this composition, directed towards another revelation of the possibilities of microphones and loudspeakers to behave like musical instruments. Davies himself calls this misuse a 'glitch': 'Here I define the "glitch" as an accidental or deliberately-caused malfunctioning of a musical instrument or item of audio-related equipment, which often has an unpredictable and potentially fruitful result; by "malfunctioning" I encompass all methods of creating sounds that were not intended by the inventors, designers or manufacturers' (Davies 2004, 2). The acoustic feedback has a life of its own which may be influenced by the performer's movements, but the sound will never be under the total control of the performer. The resistance of this musical instrument to produce its own sound and therefore becoming opaque instead of transparent is an essential feature of this composition.

Davies not only composes for this unpredictability but also makes use of the fact that the existence of this instrument is provisional. Contrary to a violin, which remains the same instrument also when not being used in a performance, the microphone and loudspeaker in a feedback set-up are in an exceptional situation and can be reconnected into another set-up. After the performers have been interacting with the feedback for nearly ten minutes, at 9′15″ something disconcerting happens in *Quintet*. The fifth player, who is controlling the volumes, switches the connections between microphones and loudspeakers.[6] The acoustic feedback sound suddenly ends, and the movements of the performers do not directly impact the sound anymore, since their microphone is now connected to the loudspeaker of one of the other performers. The instruments have been dissolved by this action, and need to be traced back again. At this point, each performer searches for acoustic feedback with his microphone by pointing it towards the loudspeakers of one of the other performers. Whereas in the first nine minutes the unpredictability lies in the instrument itself, at 9′15″ the performers have lost their instrument altogether. The hesitation of the performers during this moment is audible, even in the CD recording (Hinant 2003), although in a live performance it obviously becomes even easier to perceive, since the audience also sees the performers searching. With this radical dissolution of the instruments and the need to search for a new instrument, Davies underlines the fragility of this set-up. The instrument is not tangible, nor does it inhabit a certain location in the performance space.

In *Quintet* microphones and loudspeakers are employed according to the *tuning fork principle*. Sound is not only *reproduced*, as is the case with the *tympanic principle*, but is also shaped by the particular qualities of the microphone(s) and loudspeaker(s) used. In this chapter, I examine different methods used by composers and musicians for *interacting* with microphones and loudspeakers. These methods may be brought together by the idea that the microphone and loudspeaker themselves are audible instead of functioning only as transparent devices for transmission of sound. At the beginning of Chapter 3, I mentioned acoustic feedback as a possible result when microphone, amplifier and loudspeaker are the constitutional elements shaping the sound. However, a stable sound shaped by this set-up is not enough, since performing music implies, most of the time, that a musical instrument produces many different sounds instead of only one. How a variety of sounds can be produced with microphones and loudspeakers and what assortment of interactions might be possible between them, the performers, the audience and other elements of the set-up is the topic of this chapter.

In *Quintet*, microphones and loudspeakers are becoming sound shaping elements and thus opaque instead of transparent devices. Every component of an acoustic feedback chain acts as a filter, since it has its own characteristic spectrum, which is comparable to the situation with a musical instrument. (Emmerson 2007, 133). The different elements of an instrument can be seen as resonators, filtering out certain frequencies while others remain. A filter does not necessarily only function to diminish certain frequencies but is also able to amplify frequencies. This implies that microphones and loudspeakers add their own sound colour, just as the different parts of an instrument do. The system of microphone, amplifier, loudspeaker and space as well as the distance between microphone and loudspeaker all serve to amplify some frequencies while dampening others. By changing one of the elements of the entire system, the feedback sound will change as well. A different type of microphone or loudspeaker – changing the *material* that vibrates – will change the sound, another performance *space* influences the sound, and a change in the distance between microphone and loudspeaker through *movement* changes the resulting sound as well.

These three different aspects of modifying the sound in a feedback set-up as in *Quintet* can be recognized in conventional instrumental playing as well and are relevant in the interaction between musicians and their musical instruments. When considering conventional musical instruments,[7] *movement* is central to the interaction between performer and instrument. It is often used for supplying energy. This is accomplished by actions like bow movements, string plucking, hitting objects and blowing on reeds and into pipes. This energy generates certain physical vibrations, which act in the audible domain: objects such as strings, reeds and membranes begin to vibrate, exciting other elements, such as soundboards, to vibrate as well. I call this energy supply *movement*, as it brings the object into vibration, and the force, range or quality of movement might change these vibrations.

The alteration of the physical characteristics of the vibrating body of the musical instrument, the second action of musical instrument playing, can be achieved by, for example, shortening or lengthening strings or pipes. The exact shape of these vibrations depends on the amount of the energy as well as the material of the object brought into vibration. These different shapes of vibrations will, of course, generate different sounds, since they produce other patterns of air pressure waves. I term this second kind of action *material*, since it is the materiality of the objects that is changed and which causes a modification in the sounding result.

A third aspect of playing a musical instrument is the reaction of the performance *space*. Musicians tend to adapt their performance to the space where the performance takes place in, playing differently in a highly resonant space than in one with dry acoustics (Alperson 2008, 44). The possibilities of using spatial characteristics have become especially prominent in compositions for microphones and loudspeakers. Since loudspeakers can be mounted on the walls and ceiling, in contrary to musicians, experimenting with these sound sources in space became more prominent in music using loudspeakers. One of the most elaborate examples is the Philips Pavilion, designed by Le Corbusier and Iannis Xenakis*, in which loudspeaker set-up and architecture had been developed simultaneously. Edgar Varèse* worked on the composition for the 1958 World Expo in Brussels in which 350 loudspeakers, of which twenty-five were subwoofers, were mounted on the inner walls of the pavilion. Each track of a three-track tape could be routed to move along a so-called loudspeaker path. By isolating the walls with asbestos, a very dry acoustic response was achieved, resulting in a very clear perception of the position of whichever loudspeaker was sounding. Instead of a spatialization of the sound, this is a positioning of the sound at a specific point in space. The pavilion was shaped like a cluster of nine hyperbolic paraboloids and the shape of the loudspeaker paths was along these irregular walls (Tazelaar 2013, 157–165).

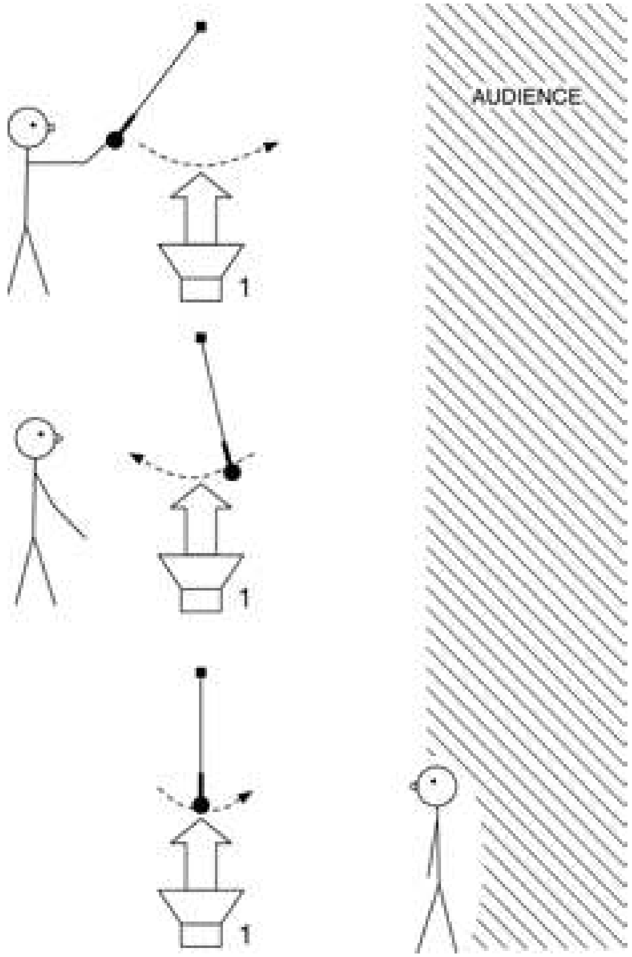
What follows is an investigation of the implementation of these interactions in the works of various composers and musicians using microphones and loudspeakers. I decided to look primarily at what could be called concert works rather than at sound installations. This might seem odd, since it is especially within the multifarious sound installations developed during the last fifty years that microphones and loudspeakers often play an important role. The reason to exclude them is that in sound installations there is no interaction between performers and musical instruments or other objects. In general, no performers are even present, and the objects used in sound installations are often not associated with musical instruments. It is for this reason too that sound installations are often regarded as being part of a fine art tradition rather than a musical one. The human–sound object interaction is most often found in the relation between the audience and the installation, which results in other types of interaction, requiring a different type of research.

Pendulum Music ***by Steve Reich: Introducing silence***

In Davies' *Quintet* the result is silence, when the distance between microphone and loudspeaker is so large that the microphone no longer picks up enough acoustic input from the loudspeaker to produce acoustic feedback—the set-up does not supply sufficient energy to maintain the acoustic feedback loop. Moving the microphone closer to the loudspeaker initiates feedback again. The closed circle previously formed by the set-up is opened slightly by this silence, since the connection between loudspeaker output and microphone input becomes much weaker. The loudspeaker still emits what the microphone is picking up, but the signal coming from the loudspeaker is, through distance, so reduced that it is insufficient to realize an acoustic feedback process. These microphone movements, approaching and withdrawing from the loudspeaker, therefore open and close the circle of this set-up, going from tuning fork principle to tympanic principle and back. The instrument is constructed as soon as the feedback sound is heard and dismantled as soon as there is silence again. *Pendulum Music* (1968) by Steve Reich* uses the appearance and disappearance of acoustic feedback as its main musical material (Scheme 4.2). Several microphones hang above an equal number of loudspeakers, lying with diaphragms facing up on the floor (Reich suggests 2, 3, 4 or more in the original score (Nyman 1999, 12), see scheme *Pendulum Music*). At the beginning of the performance, each performer takes a microphone in her hand, pulls it to the side and releases it to swing directly over the loudspeaker. Next, the volume of the amplifier is turned up, until a soft feedback sound can be heard. The microphones swing forwards and backwards.

Whereas the phasing effect caused by the microphones swinging back and forward at different speeds was probably the main compositional interest for Reich himself, I will investigate what happens with the feedback sound during this performance. The feedback only occurs when the microphone is close enough to the loudspeaker. At the beginning of the performance, a large part of the arc created by the swinging movement of the microphone takes place in total silence. Only when the microphone is quite close to the loudspeaker a short feedback sound is audible, seemingly appearing out of nowhere. This feedback sound primarily consists of only one pitch. When the movement of the microphone becomes smaller and slower, the feedback sounds become longer, but often more varied as well, since the microphone remains closer to the loudspeaker, and there is more time for sounds to develop. Although the arc of the microphone pendulum becomes smaller and smaller, the feedback sound increases in length as well as in variation of pitches and sound colours, depending on the distance between microphone and loudspeaker, and the velocity of the microphone movements. At the end of the piece, all microphones hang motionless above the amplifier, and the feedback sound stabilizes to become a continuous sound.

The sound sources of what is audible are microphone, amplifier and loudspeaker. The interaction with the performer takes place only at the very beginning in complete silence, since the volume is not yet raised to a level that creates feedback. The biggest movement, the first swing of the microphone after the performer releases the microphone, takes place before any sound occurs. Starting with an open space of silence, this piece closes towards a circle of feedback sound. The instrument comes into being during the performance, seemingly appearing out of nowhere. Reich requests the performers explicitly in the score to watch and listen to the process along with the audience, once they have released the microphones (Nyman 1999, 12).



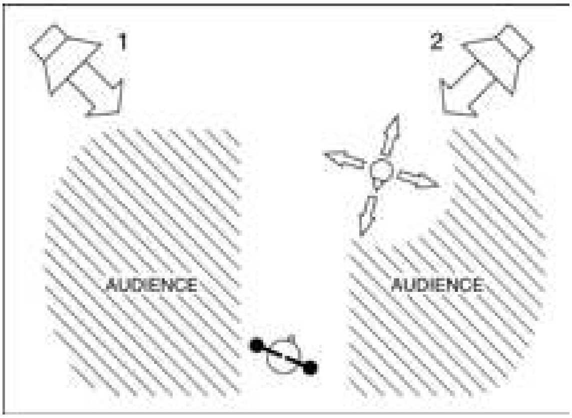
Scheme 4.2 Steve Reich *Pendulum Music*: the scheme depicts three stages of the piece. At the top the performer is holding the microphone, in the middle the performer has released the microphone and at the bottom the performer has joined the audience to listen to the swinging microphones.

Nobody is playing after the first release of the microphones. What happens is that, with every swing of the microphone, more of the sound appears, more of the sonic potential lying dormant within the system of microphone, amplifier and loudspeaker. Contrarily to the interaction with conventional musical instruments, which need to be compelled through with movements by performers to reveal their musical world, this piece seems to reveal more of its musical world as less movement occurs. There is no resonance or resistance in this set-up which has to be discovered by playing the instrument. The performers sit down to listen to how the musical instrument develops, when it is not being forced to produce sounds but allowed to discover its own sound world. Using acoustic feedback in a composition can stimulate forms of *interacting* between performer and sounding object which are substantially different than those arising in performances with conventional musical instruments.

Bird and Person Dyning *by Alvin Lucier: Listening as a performative act*

Apart from turning the feedback on and off by changing the distance between microphone and loudspeaker, as in *Pendulum Music*, one might imagine as well that the microphone picks up not only the sound of the loudspeakers but that of another sound source as well, as is done in *Bird and Person Dyning* (1975) by Alvin Lucier*, for example (Scheme 4.3). The silence caused by opening the feedback circle is now intruded upon by another sound producer, which enters from outside the feedback set-up.

Listening itself becomes a performative act within this piece. A small electric bird chirps in the space, and the performer, often Lucier himself, moves his head as if trying to locate the bird by listening to its song. He wears binaural microphones in his ears, and the sound picked up by these microphones is emitted through one or more pairs of loudspeakers. The pair of loudspeakers is necessary since the signal is stereophonic, as the microphones are picking up a signal from each ear. As mentioned in the score, the amplifier's level should be high enough to provoke feedback (Lucier 1995, 372). Since the feedback sound is related to the distance between the microphone and loudspeaker and the reflections of the sound in the performance space, there is a clear *interaction* between performer movements and resulting sound, as in *Quintet* and *Pendulum Music*. Every movement of the performer's head results in a change in the feedback



Scheme 4.3 Alvin Lucier *Bird and Person Dyning*: the sound of the electronic bird is picked up by the microphones in the ear of the performers. The microphone signal is emitted by the loudspeakers and depending on the distance between microphones and loudspeakers acoustic feedback is produced as well.

sound. At the same time, the bird is also amplified through the microphones, located in the ears of the performer, and the amplified sound of the bird also interacts with the feedback sound. The binaural microphones pick up the direct electronic bird sound as well as all its reflections in the performance space. These are again projected into the performance space through the loudspeakers and influenced by reflections in that space, resulting in complicated patterns of interferences of sound waves, also resulting in what are commonly called sum and difference tones.[8] Lucier uses the more technical term *heterodyning*[9] for this effect, hence the title also refers to this through the word 'dyning'.

The sound in this piece is shaped not only by the distance between performer and loudspeaker but also by that between performer and bird. Lucier makes movements that signify listening or, as he himself says, 'do you know how robins turn their heads to listen?' (Lucier 1995, 172). Lucier describes the task of the performer as follows:

> The performance simply consists of the performer moving slowly around the space searching for phantoms. When I perform the work I usually move trough the audience, toward the birdcall and speakers, stopping briefly when I hear heterodyning. I tip my head from left to right, to fine tune the results and move them to various points in space. The spatial relationships between the binaural microphones and the loudspeakers determine the geographical locations of the phantom birdcalls. I relish the theatricality of the situation. Sometimes the results are vivid – transpositions and their mirror inversions occur. At other times, however, the room just produces a few unwanted resonances. The performer accepts the task of finding the appropriate strands of feedback that create phantom images of the birdcall. The performance is not an improvisation. (Lucier 2002, 24)

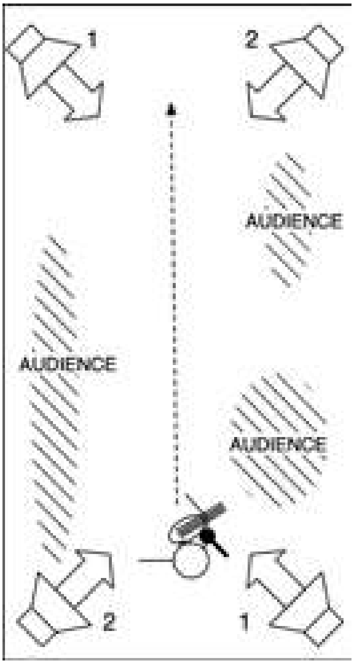
The performer's listening is now an audible feature of the performance. In contrast to Reich's *Pendulum Music*, there is a constant interaction in *Bird and Person Dyning*, between movements by the performer and the resulting sound. This interaction does not rely on the gestures of conventional instrument playing, as does most of the piece *Quintet* by Davies. The movements incorporated in this piece are derived from, and thus denote, the practice of listening, which is often regarded as being silent and passive. The bird plays the role of the more conventional musician during this performance, but its way of making music is quite predictable: the bird repeats exactly the same phrase, again and again. The variable part of the performance is more present in the actions of listening performed by Lucier, generating constant changes in the sound result, since the reception of the bird sound as well as the feedback sound itself changes according to the head movements.

What happens when microphones and loudspeakers are actively taking part in a musical performance is a change in performance praxis itself. The kind of *interaction* between performers and microphones and loudspeakers is often quite different from what commonly takes place in a musical performance with conventional musical instruments. The performers are 'looking for their instrument', as in *Quintet*, 'listening to their instrument', as in *Pendulum Music*, or 'using their listening as a sound controlling act', as in *Bird and Person Dyning*. Microphones and loudspeakers can thus be part of a musical performance, and performers can interact with them. Owing to their resistance to acting in ways we expect of conventional musical instruments, they twist the familiar elements of a performance into a new configuration.

Green Piece *by Anne Wellmer: Interacting with another sound source*

In the first two examples, the sound is shaped entirely by microphone, amplifier and loudspeaker as well as the performance space itself. There was direct communication between loudspeaker and microphone; neither could be identified as the initiator of the chain of sound production. In the last performance *Bird and Person Dyning*, this system is expanded through the introduction of the little electronic bird. When this bird calls, the microphones pick up a signal which changes owing to something other than the performer's movements. The electronic bird is not part of the microphones and loudspeaker set-up. The microphone turns aside from the loudspeaker as its only partner for shaping the sound and picks up the vibrations of another object. The circle of feedback is opened, and a starting point for the sound, namely the electronic bird, is introduced. Whereas the feedback sound in this performance is still a circle without a clear starting point or end point, there is also what I would like to call a 'line of amplification' present in this piece. The electronic bird initiates this line, which is subsequently extended by the microphones picking up its sound, and which finishes with the loudspeakers emitting the sound in the performance space.

In *Green Piece* (2006) by Anne Wellmer* (Scheme 4.4), a viola player wears a wireless microphone, and four loudspeakers are placed in the hall. The loudspeakers do not get each their own signal, as was the case in the pieces discussed until now, but the set-up is a crossed two-channel set-up. There are two audio channels that are diffused through diagonally opposite loudspeakers. As in Lucier's piece, the performer walks around during this piece, and when approaching a loudspeaker, feedback is caused as well as when retreating, the feedback is thus diminishing. The viola player has tuned the two lowest strings of the viola to G and should bow anywhere on the G-strings, looking for overtones to sound. The musician has to slowly explore the performance space, moving from one end of the hall to the other. *Green Piece* has originally been written for a long hallway with green tiles. Tiles reflect sound waves very well, since they have a very smooth surface. For many more conventional musical performances such a space would acoustically not be suitable at all, since it would add strange resonances, but these are exactly the effect Wellmer is looking for. Depending on the space, the feedback reaction is quite different, and Wellmer explains that according to the space, the performer has to adapt her movements: 'In a large space the smallest movement might change the pitch. A small space might require quick change of position and direction on the spot in order to change the sound' (Wellmer 2005, 2). The viola player should know the feedback reactions of the hall well enough to be able to influence the feedback and therefore knows which movements cause (approximately) what kind of modifications in the feedback sound. Because the vibrations of the viola are continually received by the microphone, which is attached to the viola, the performer



Scheme 4.4 Anne Wellmer *Green Piece*: the sound of the viola is picked up by a microphone. The microphone signal is emitted by the loudspeakers and depending on the distance between microphone and loudspeakers acoustic feedback is produced as well.

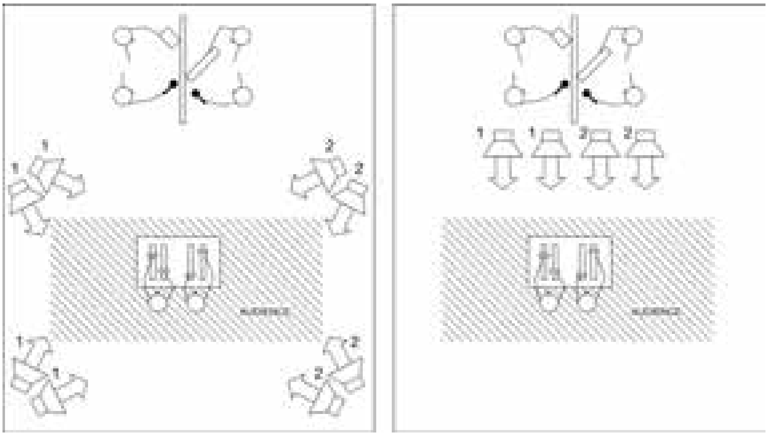
is able to influence the feedback. If the viola plays certain sounds, feedback will be triggered in response to these frequencies or related frequencies. Additionally, fixed sounds are played through the loudspeakers, which will also modify the feedback. The instability of the acoustic feedback set-up is exploited by Wellmer as a means to create live electronic sound processing, shaped by a constant interaction between viola, microphone, loudspeaker and performance space. The feedback is no longer functioning in the performance as a central phenomenon, but in constant dialogue with the sounds of the viola. Whereas in Lucier's piece the electronic bird sound was not influenced by the acoustic feedback, in the piece by Wellmer the viola reacts to what is happening sonically as the result of acoustic feedback.

Mikrophonie I *by Karlheinz Stockhausen: Amplification only*

It becomes clear from the last two examples – the pieces by Lucier and Wellmer – that in applications other than acoustic feedback, such as amplification, microphones and loudspeakers can become audible as sound shaping devices as well. Varying the distance between microphone and a sound source will not only make the latter louder or softer, but also different in sound colour. When the microphone is further away from the sound source, more resonances of the space will be picked up, whereas when it is closer to the sound source, more high partials of the sound of the object and less space resonance will be introduced into the sound produced. In this way, it is possible to compose a piece in which movements of the microphone are the only changing parameter, without the occurrence of any acoustic feedback.

In *Mikrophonie I* (1964) by Karlheinz Stockhausen* (Scheme 4.5), microphone movements which result in differences in amplification are used as an important part of the composition, as already revealed by the title. Stockhausen's inspiration for this piece came from listening closely to the sounds of the tam-tam and realizing that he heard all kind of sounds that would remain inaudible for the audience if they were not amplified (Manion, n.p.). He decided to use a microphone as a replacement for the ear. Although the microphone should fulfil a listening function in this piece, similar to the role of the microphones in *Bird and Person Dyning*, there is a significant difference here. The microphones are treated 'as a doctor who probes a body with a stethoscope', as Stockhausen mentions in the preface of the score (Stockhausen 1964, 9). Whereas Lucier's piece focus on the subjectivity of listening, making audible the listening of an individual, Stockhausen seems to be more interested in discovering the intimate realms of the sound of the tam-tam, which would remain unheard without the help of a microphone.

Stockhausen conceived *Mikrophonie I* (Figure 4.1) as a piece in which the microphone is put to use as a musical instrument. He searched for a way of eliminating the fixed microphones on stands which always maintain the same distance from the instruments they pick up. In *Mikrophonie I*, Stockhausen aspired to bring the position



Scheme 4.5 Karlheinz Stockhausen *Mikrofonie I*: microphone movements are used to pick up tam-tam sounds. The left is diffused by the loudspeakers at the left side of the hall, the other at the right side. The scheme at the right depicts the original plan to place the loudspeakers as close as possible to the tam-tam.

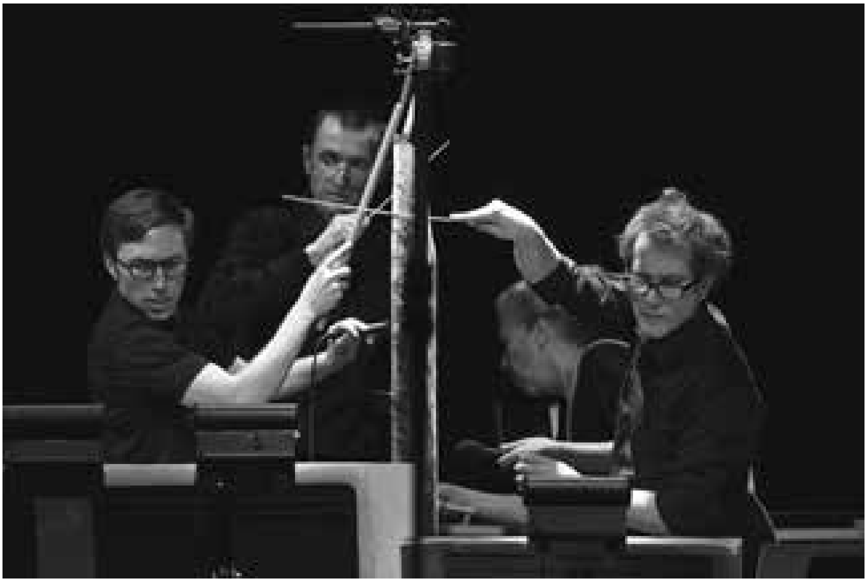



Figure 4.1 The Talea Ensemble performing Stockhausen's *Mikrophonie I*. Photo by Michael Yu.

of the microphone into play as a composable parameter. He describes his compositional intentions as follows:

> The microphone has, up to now, been treated as a lifeless, passive recording instrument for the purpose of obtaining a sound playback that is as faithful as possible: now it also had to become a musical instrument, and to be used in turn to affect every aspect of sound. Thus it had to be able to contribute to shaping pitches, harmonically and melodically, also rhythm, dynamic level, timbre and spatial projection of sound, according to composed indications (Stockhausen 1964, 9).

The microphones should be used to modify the same parameters as every conventional musical instrument is able to do and guide all aspects of sound shaping. The result is indeed probably one of the most elaborate scores for movements with microphones ever written. *Mikrophonie I* is scored for tam-tam, two microphones, two filters and potentiometers, and should be performed by six players. These players are divided into two symmetrical groups, each comprised of one player who causes the tam-tam to sound by manipulating it with different objects; one player who picks up, with a highly directional microphone, the sounds produced by the first player as well as occasionally playing the tam-tam with objects; and a third person controlling the filter and potentiometers for the final sound result diffused in the performance space. At each side of the tam-tam there is an object player and a microphone player; the filter and fader players are positioned in the audience space. By dividing the musical process into these three different areas, Stockhausen sees the possibility of connecting all aspects of instrumental praxis with the electronic sound world. For him, through using a microphone and processing the sound it picks up, the vibrations of any sounding object receive the possibility of merging into a coherent music composition (Misch and von Blumröder 1998, 119). His way of achieving this is, first of all, to deliver the microphones into the hands of the musicians. In the score of *Mikrophonie I*, Stockhausen notates diverse movements for the microphones. The two main parameters described are the distance to the tam-tam surface; three different distances are defined, from very close to far away as well as the distance of the microphone to the point of excitation by the object used to play the tam-tam, most of the time played by player one. This second parameter is also divided into three different distances: direct sound from the object, sound from further away, and indirect sound. The closer the microphone is to the object, the more prevalent high frequencies will be in the sound, since rapid air pressure waves decay the fastest. When the microphone is placed further away from the object, there will be not only fewer high frequencies but also more sound input from the space present in the resulting sound. Whereas the loudest and sharpest sound will possibly be transmitted when the microphone is held very close to the object as well as the tam-tam, there will be a decreasing scale of high frequencies and also amplitude of the sound. The score requires rapid and virtuoso transitions between all these positions. Obviously, these kinds of changes in sound cannot be obtained by simply moving the volume slider of the microphone input at the mixing desk, since that would only change the amplitude of the signal without changing any of its spectral qualities.

The sound produced with these microphones is emitted preferably over eight loudspeakers surrounding the audience. This loudspeaker set-up was developed by Stockhausen to provide every audience member a stereo image of the sound, instead of just the few people sitting in the so-called sweet spot. There are three sweet spots now, instead of only one (Stockhausen 1996, 78). There is no stereophonic signal in *Mikrophonie I* though, since the microphones are not placed according to a stereo set-up, so in this case the extra loudspeakers are providing a stronger left and right division of the signal. This was certainly not how the loudspeakers were placed when this piece was developed and had its first performances. As Hugh Davies remembers, they had to give up the plan for premiere in 1964 of 'having loudspeakers only very near the tamtam, at the front of the stage with all the sound coming from the same direction' (Davies 1968, 11). Evidently these close distances between the loudspeakers and microphones caused, in this case undesirable, acoustic feedback. To fill the whole hall with sound an extra loudspeaker was placed in a balcony on each side of the stage. As Stockhausen mentions, the audience should hear primarily the sound of the loudspeakers, and only at very intense moments the direct sound of the tam-tam (Maconie and Stockhausen 2010, 79). When using the loudspeaker set-up mentioned in the score, the loudspeakers at the audience's right side amplify the front microphone (placed at the right side of the stage), and the left loudspeakers amplify the microphone at the back side of the tam-tam (placed at the left side). In this situation, the sound perspective of the audience becomes far removed from an unamplified auditory perspective of the tam-tam. At both sides the audience hears a tam-tam, and with every microphone gesture they are – in terms of sound – moving closer or further away from the tam-tam and the object that is manipulating the tam-tam. Movements of the right and left side, as conveyed by the loudspeakers might be completely different. In the end, what is heard is neither solely the amplified tam-tam and objects nor the microphone movements alone, but a complex sound world that is the result of all those elements together. Stockhausen himself described these sounds without any reference towards the tam-tam or the microphone: 'We heard all sorts of animals that I had never heard before, and at the same time many sounds of a kind I couldn't have possibly imagined or discovered, not in the twelve years I had worked in the electronic music studio up to the time of that experiment' (Maconie and Stockhausen 2010, 78). The enormous discrepancy between sound input (the tam-tam) and the output through the loudspeakers is what Stockhausen calls the *microphonic process* (Maconie and Stockhausen 2010, 78). The resulting sound seems to no longer refer to the tam-tam, but to create a totally new sound world. Evidently, this is not only owing to the microphone movements and loudspeaker amplification. The filters used also alter the tam-tam sound considerably.

In the pieces by Lucier and Wellmer, the line of amplification initiated by the sound-producing object is an amalgam with the circle of feedback. Each influences the other and there is no clear division between the two processes. In technical terms, both are the same, since feedback occurs because of a high amplification level. The level of amplification is controlled in Lucier's and Wellmer's pieces by the movements of the performer, changing in this way the distance between microphones and loudspeakers. Nonetheless, regarding what is recognized as the semantic sound source, it is possible to make a distinction between 'sound coming from the bird or the viola, and amplified through the loudspeakers' and 'feedback sound, coming from nowhere'. There is no certain localization of feedback sound, as demonstrated by *Quintet,* and the sound seems to be produced by musical instruments that appear out of nowhere, as in *Pendulum Music*. The source of the bird and viola sounds can be easily localized and attributed to the bird and viola. The amplified sound emitted by the loudspeakers points towards those objects. This amalgam of two different forms of sound production is dissolved in Stockhausen's *Mikrophonie I*, since the starting point of all sounds heard through the loudspeakers is the tam-tam and no feedback is used here. The difference between the circle of feedback and the line of amplification is therefore not only a mere difference in technical set-up but above all a difference in interacting with musical instruments.

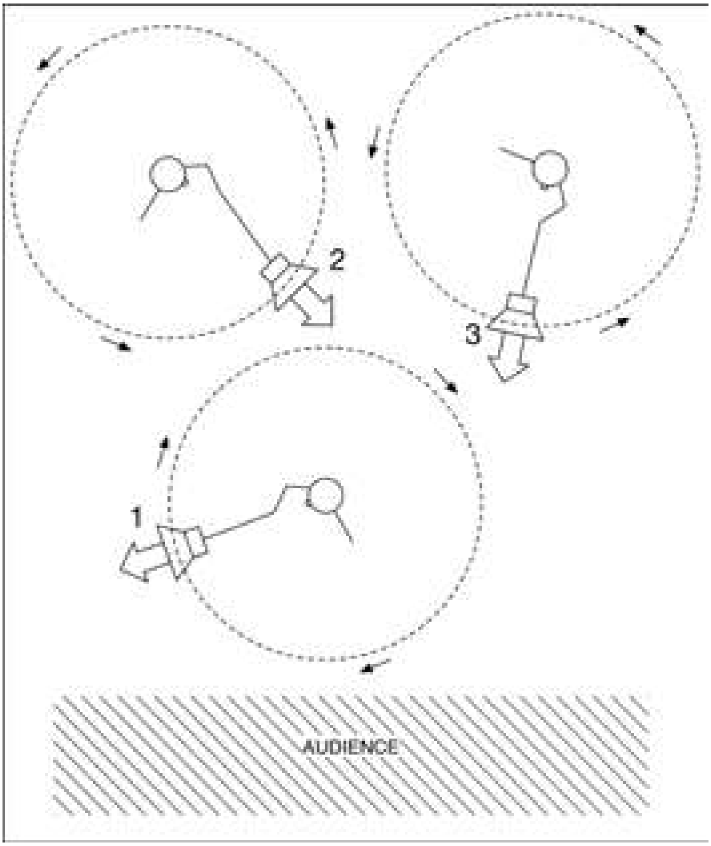
Stockhausen, in a way similar to Davies in *Quintet*, is attempting to transform the microphone into a musical instrument, since both he and Davies use microphone movements to influence the sounding result. The circle of feedback is broken in *Mikrophonie I*, however, and has become a linear process, with a clear starting point (the objects manipulating the tam-tam), further sound shaping (microphone reception and subsequent filtering by the third performer) and a clear end point (the radiation of the sound through the loudspeaker). As Stockhausen mentions explicitly in the score, feedback should be avoided by placing the front loudspeakers as far away as possible from the tam-tam (Stockhausen 1964, 9). The similarity between the approaches of Stockhausen and Davies are by no means accidental, since Davies actually performed one of the filter-playing parts during the first performances of *Mikrophonie I*. He might have acquired his first ideas for *Quintet* during a *Mikrophonie I* rehearsal, when acoustic feedback happened accidentally.

In *Mikrophonie I*, the microphones serve in the process of amplifying the sounds, a very common use of microphones, as heard in many other applications. But should this line of amplification, leading towards a certain sound-producing object, not be regarded as a form of the *supporting* approach? Should it be said that the use of the microphones in *Mikrophonie I* is more instrumental or interactive than, for example, when used for the amplification of singers? Why could a singer such as Ella Fitzgerald not being seen as 'playing' the microphone, as she also changes the distance between her mouth and the microphone to change the quality of the vocal sound?

First of all, as I stated in Chapter 2, when introducing the four approaches *reproducing*, *supporting*, *generating* and *interacting*, these are no rigid classifications but different theoretical models. For many singers, the microphone is a prolongation of their voice, and the microphone is in that case *supporting* the voice. A singer does not need to notate the microphone movements he or she is making, since they rehearse their microphone use as a core element of their singing practice. They develop a personal repertory of microphone techniques to complement and augment their vocal techniques, and often have a favourite type of microphone. In *Mikrophonie I*, microphones are neither a prolongation of the musical instrument nor devices to support the tam-tam character; on the contrary, they seek to discover a sound world in the tam-tam that which would otherwise remain inaudible. The amplification in Stockhausen is often in counterpoint to the sound produced by the tam-tam. Whereas the sound of the tam-tam slowly fades out, for example, the microphone is moved rapidly back from and towards the tam-tam, resulting in a fast fade in-fade out-sound emitted by the loudspeakers. The microphone transmits a voice of its own, instead of 'only' *supporting* another voice. Whereas in the *supporting* approach the line of amplification points straight towards the object or person producing the sound, in *Mikrophonie I* this line is full of twists, turns and curves. These lines of amplification manage to create semantic acts of sound creation which seem to come from something else than the original amplified tam-tam (these acts are described by Stockhausen as 'all sorts of animals that I had never heard before'). There is an audible difference between a *supporting* amplification and an *interacting* amplification. Of course, there is no reason that singers would not use this *interacting* form of amplification as well, and I would argue that many singers do use several forms of *interacting* amplification next to *supporting* amplification. That these kind of combinations of several approaches can be even used as compositional strategies is what I will explain in Chapter 5, for example by singer Ute Wassermann in her piece *Windy Gong*.

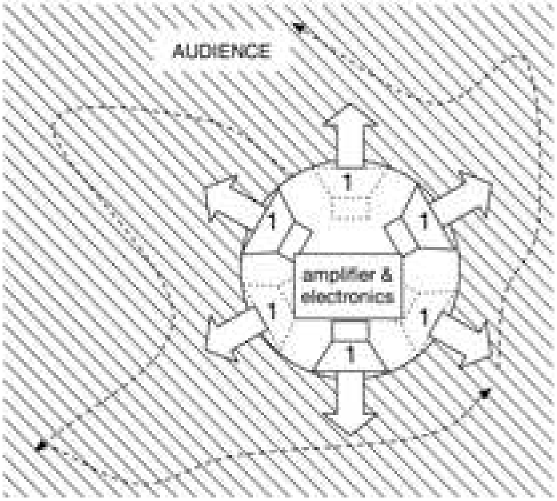
Speaker Swinging *by Gordon Monahan and* Three Short Stories and an Apotheosis *by Annea Lockwood: Moving loudspeakers*

In *Mikrophonie I*, the tam-tam is the starting point of the line of amplification. The modifications of this line, which serve to make the amplification *interacting* instead of *supporting*, are principally shaped by the movements of the microphones. The loudspeakers radiate this sound in the performance space but do not move themselves. Two examples which serve to illustrate a form of *interaction* with *movement* initiated by loudspeakers instead of microphones are *Speaker Swinging* (1982) by Gordon Monahan* (Scheme 4.6) and *Three Short Stories and an Apotheosis* by Annea Lockwood* (Scheme 4.7) . In *Speaker Swinging*, each of three or more performers swings one loudspeaker connected to a rope (Figure 4.2). The loudspeakers are connected to eight audio oscillators that generate sine and square waves. Different acoustic effects occur as a result of the rotary motion of the speakers, the Doppler effect, for example.[10] The loudspeaker itself should become audible through the fast movement, becoming a musical instrument, as Monahan says himself: '*Speaker Swinging* grew out of a desire to animate the typical electronic music concert and in effect, to realise the loudspeaker as a valid electronic music instrument in itself' (Monahan 1982).



Scheme 4.6 Gordon Monahan *Speaker Swinging*: three performers swing a loudspeaker.

Figure 4.2 Loudspeaker set-up for *Speaker Swinging*: besides the loudspeaker also a light and a device for controlling the light is attached to the rope. © Gordon Monahan. Photo by Beat Müller.



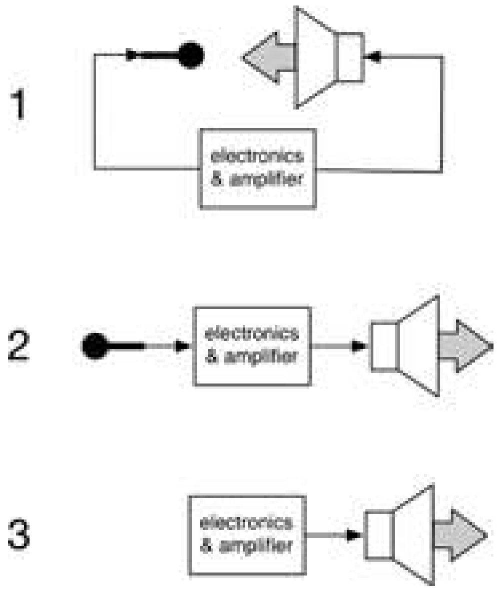
Scheme 4.7 Annea Lockwood *Three Short Stories and an Apotheosis*: a Sound Ball with six loudspeakers is thrown by the audience.

Annea Lockwood moves sound in a particular way through space by means of a Sound Ball, consisting of six loudspeakers, six amplifiers, six filters and a radio receiver, which receives a mono audio signal, so that all six loudspeakers in the ball receive the same audio signal (Figure 4.3). The ball was built by Robert Bielecki. As Lockwood explains, she decided to use a mono signal to make the movements by the ball more audible than would be the case when two different signals were used (Amirkhanian 1986, n.p.). She has used this ball in performances with dancers and she performed herself the piece *Three Short Stories and an Apotheosis* (1985) for Sound Ball and pre-recorded sounds. In this piece, the Sound Ball is given to the audience, the members of which also become performers, by taking the Sound Ball and passing it on to someone else. A clear change in performance practice occurs here as a result of using loudspeakers as the main sound-generating element in a piece of music. The audience is 'playing' with the Sound Ball, which however is not treated as a musical instrument, but as a ball in sport games. To underline this everyday aspect of the performance of the piece, Lockwood projects a double image of a woman tossing a ball which looks very similar to the ball she is using.[11] By moving loudspeakers through space, as in these pieces by Monahan and Lockwood, they easily become identifiable as the source of the sound. The audience can clearly attribute the changes in sound to the loudspeaker movements. The presence of the loudspeakers and their role as sound-producers is revealed by having them moved by performers (*Speaker Swinging*) or by giving them to the audience themselves (*Three Short Stories and an Apotheosis*). At the beginning of this chapter, in *Quintet*,

Figure 4.3 The inside of the *Sound Ball* by Annea Lockwood. © Annea Lockwood. Photo by Manny Albam.

the musical instrument in the acoustic feedback set-up could not be localized; here the instrument has become an object that can be traced by the ears and held in the hand.

These last two pieces could best be described as using microphones and loudspeakers as a point of radiation, rather than as a circle of feedback or a line of amplification (Scheme 4.8). The sound emitted by the loudspeakers could be recognized as either being part of the *reproducing* approach (the pre-recorded sounds used by Lockwood) or the *generating* approach (the sine and square wave generators used by Monahan). However, the sound is radiated by loudspeakers, which become opaque and are recognizable as the semantic source of the sound waves. Whereas in the common *reproducing* or *generating* approaches, the direction of radiation of sound waves from the loudspeakers is always from the same position, since the sound should be conveyed to the space and the listener in such a way that the loudspeaker is as transparent as possible, in these two pieces the point of radiation is modified by movement. Not only are the position and direction of the sound sources modified, but, owing to changes in distance as well as speed of motion, changes also occur in the frequency spectrum as perceived by the audience. In contrary, the line of amplification points towards one or more sound-producing objects. Thinking of *Mikrophonie I*, even when the sounds remind one of 'animals I had never heard before', all sounds will ultimately be associated with the tam-tam, as their 'original' source. A point of radiation does



Scheme 4.8
(1) A circle of feedback.
(2) A line of amplification.
(3) A point of radiation.

not include another sound-producing object in the performance and can therefore be regarded as the starting and the end point of the sound. For this reason, microphones are excluded from the set-up (a microphone always 'points' to an object). These two concepts – point and line – are united within the circle of feedback, where there is no starting nor end point.

At the beginning of this chapter, the microphone was facing the loudspeaker and thus generating acoustic feedback, due to proximity. The output was the input, and all elements were interconnected by a feedback loop. This set-up was played by changing the distance between microphone and loudspeaker in *Quintet*. The microphone moved further and further away from the loudspeaker in pieces like *Pendulum Music*, *Bird and Person Dyning* and *Green Piece*. There were moments in which the distance between microphone and loudspeaker was so great that acoustic feedback no longer took place. In *Bird and Person Dyning* and *Green Piece*, the microphone was picking up another sound source alongside that of the loudspeaker(s), the electronic bird sounds and the viola playing, respectively. In *Mikrophonie I*, the microphones were turned away from the loudspeakers during the entire piece, so no acoustic feedback took place; the microphone was made opaque through movements to and from another sounding object, a tam-tam in this case. Owing to changes in distance between microphone and loudspeaker, caused by movements of the performers, the acoustic feedback disappeared, and other objects instead were amplified through the loudspeakers. Slowly the acoustic feedback circle was opening and developing towards an instrument which might be described in terms of a linear process of amplification, resulting in a single source for the radiation of sound. This linear process emphasizes the *material* quality of the semantic sound source, either because it is amplifying a specific sound-producing object (bird, viola or tam-tam in the examples above) or because the presence of the commonly transparent sound source, namely the loudspeakers, is exposed.

Material

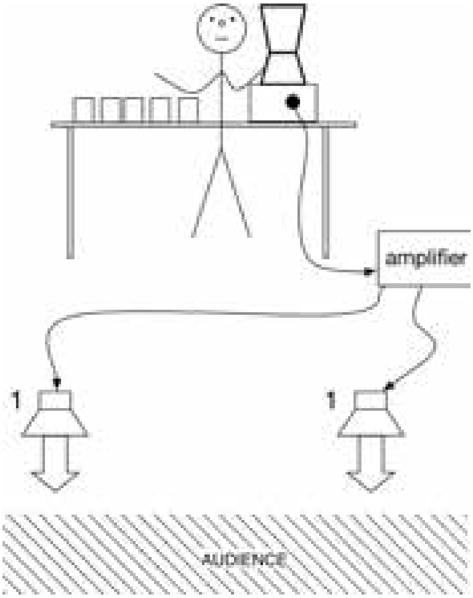
Following this development from circle of feedback to line of amplification and radiation of sound, the next step would be to approach the amplified object even closer, until object and microphone are as close as possible. A way of achieving this is by the use of a contact microphone,[12] since this is, as its name indicates, touching the material that it is amplifying. There is no longer any air between diaphragm and object. The *interaction* between performer, and microphone and loudspeaker can no longer be revealed through movements of the microphones, since the microphones are attached to the material of the object itself. It is the material of the diaphragms themselves as well as the material that they are touching which makes the microphones or loudspeakers audible. Microphones and loudspeakers do not move anymore, but reveal their instrumentality in response to the sound characteristics of their material. This is the second parameter of musical instrument playing I mentioned at the beginning of this chapter: modification of the physical characteristics of the vibrating body of the musical instrument.

Coffee making by Valerian Maly and 0′00″ *by John Cage: Everyday actions amplified*

Once every year, Valerian Maly* makes coffee for his new students (Scheme 4.9). An activity known from everyday life, with a small change: a contact microphone is attached to the coffee-making set-up, amplifying the vibrations of this set-up through loudspeakers. The sounds made during this coffee-making process therefore differ from what is usually heard, thus attracting the attention of the students waiting for their coffee, who then begin to listen to and look at this well-known action in a different way. The use of contact microphones results in Maly's coffee-making becoming a (musical) performance instead of an everyday action.

Maly's coffee-making performance could be seen as a performance of *0′00″* (1962) by John Cage*. The main instruction for this piece in the text score is: 'In a situation with maximum amplification (no feedback), perform a disciplined action' (Pritchett 1993, 138). Cage himself describes this piece as being

> Nothing but the continuation of one's daily work, whatever it is, providing it's not selfish, but […] the fulfilment of an obligation to other people, done with contact microphones, without any notion of concert or theatre or the public, but simply continuing one's daily work, now coming out through loudspeakers (from an interview with Lars Gunnar Bodin and Bengt Emil Johnson, 1965, cited in [Kostelanetz 2002, 74]).



Scheme 4.9 Valerian Maly cooking coffee: a contact microphone picks up vibrations of the set-up used for cooking coffee.

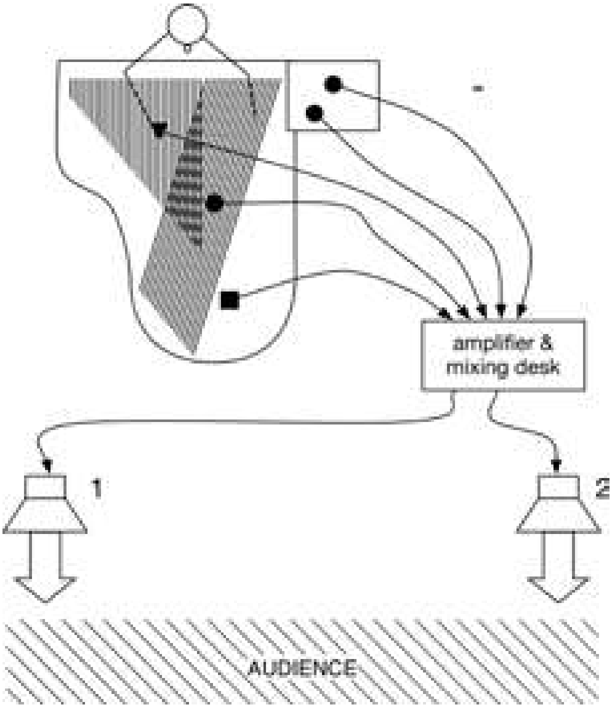
Cage makes two important discoveries for his work during the 1950s: all sound has the possibility of being part of a performance (resulting in the composition *4′33″*), and sound is always present, as he discovered by entering the anechoic room and still hearing the sounds of his own body (Kahn 1999, 158–159). The full title of *0′00″* is *0′00″ (4′33″ No. 2)*. *0′00″* can be seen as a second *4′33″*, this time not about 'all sound', though, but 'always sound'. Cage describes the aim of amplifying an everyday action as following: 'What the piece tries to say is that everything we do is music, or can become music through the use of microphones; so that everything I'm doing, apart from what I'm saying, produces sound. When the sounds are very quiet, they become loud through the use of microphones.' Cage expands this idea of always sound and claims that amplification transforms all sounds into music: 'The only reason for amplification is that it's in the field of music. By means of electronics, it has been made apparent that everything is musical' (both citations of an interview with Lars Gunnar Bodin and Bengt Emil Johnson of 1965, cited in [Kostelanetz 2002, 74]).

Cage's idea that amplification of sounds would implicitly make them musical is interesting in the context of *interaction* with microphones and loudspeakers, since this idea might imply that the simple use of amplification could turn every possible object into a musical instrument. Amplification, whether with contact microphones or other microphones, condensers for example, is a common practice in Cage's work. Pieces such as *Cartridge Music* (1960), *Child of Tree* (1975) and *Branches* (1976) use amplification as one of their main compositional elements.

Contact microphones as used in Maly's coffee-making performance pick up vibrations from solid material at the point of attachment to that material. These vibrations are quite different from the vibrations radiated into the air by the whole object. Contact microphones are especially suitable for objects which can support strong vibrations in their material, but which do not radiate these vibrations into the air very well: solid objects, such as a table. The vibrations of the table stay inside the table, since the table is not flexible enough to transport these vibrations to the air. Musical instruments could be seen as revealing the opposite characteristic: they tend to radiate their vibrations very well into the air, which is why they produce relatively loud sounds. Owing to the high amount of vibrational energy which remains inside the object, many everyday objects, like chairs, tables or kitchen utensils, are well suited to amplification with contact microphones.

Since contact microphones are connected to a specific point on the solid material, only the vibrations at this point will be amplified. These vibrations can vary extensively at different points on the object, and can also differ considerably from how the object sounds in its entirety. There will probably be fewer frequencies present in a specific point of contact with the material, picked up by the contact microphones, than there are in the total sum of vibrations radiated by the object into the air. Thus the amplified sound contains fewer frequencies and a stronger presence of pitched material compared to the unamplified sound, which reveals a wider variety of frequencies in its spectrum and therefore a noisier sound. Apart from that, contact microphones themselves often have pronounced resonance peaks of their own at specific frequencies (Hopkin 2002, 7), so the pitched character of the sound is further accentuated by the material of the microphones themselves as well. Besides, the vibrations of an object might be difficult to transmit to the air, and thus sound quite softly without amplification, but become loud when a contact microphone is used. Contact microphones are for these various reasons often described as not of very high quality or even unnatural (Hopkin 1996, 164) or as filtering the spectrum of the sound by amplifying certain partials more than others, often called 'colouring' the sound, to an extreme degree (Emmerson 2007, 132). This process is very similar to what happens when a musical instrument is played – it filters the energy supply of the performer and amplifies these filtered waves (often this filtering by musical instruments is so strong that only a harmonic spectrum is left). The contact microphone fulfils the same role in the coffee-making performance: it filters the input energy and amplifies the remaining frequencies.

This process of filtering and amplifying adds a resonating body to material which lacks one of its own. Unusual material, like a coffee-making set-up or the metal skirt worn by Ellen Fullman* in her performance *Soundwalker* (1980),[13] therefore behaves similarly to a musical instrument. The sounds made by ordinary objects and ordinary actions are unified through sharing common resonant characteristics, acquired as a result of their amplification with contact microphones. Amplification of certain frequencies has a very long tradition in our musical culture, and it might be useful to take a short look at this tradition in order to understand why this resonance might be perceived as musical. Early humans tended to hold music performances in caves, the resonances of which amplified certain frequencies in the sounds they produced. Apparently these older cultures 'made no distinction between objects actively producing sound, such as bells, and objects passively modifying those sounds, such as a cave' (Mithen 2005, 75). They probably regarded the sounds added in caves as a result of the reflections of the walls as voices or spirit from a world beyond the cave wall (Mithen 2005, 75). The cave modified the sound of the objects by adding resonance and in this way changing well-known everyday sounds into unusual sonic experiences. Through the use of contact microphones, all objects can acquire a sound which seems much larger and more artificial than that of the object without amplification. Due to amplification, these objects can be recognized as producing musical sounds, instead of ordinary sounds known already in everyday life. The extensive use of amplification, filtering and reverb – all three, in fact, take place with the use of contact microphones – in many forms of music nowadays could therefore be seen as a form of merging the different sound colours of the source material. This does not mean, though, that every sound is considered to be music, simply through the use of amplification. A person talking through a microphone is often not associated with music at all. Concerning the pieces by Cage which use amplification as the main means of making music out of everyday material, it becomes clear that much more is needed to make music out of it. One of the main arguments might be that Cage is largely exploring sounds which are perceived very differently when they are not amplified, and incorporating these sounds within a musical performance context. The amplification should not be understood as underpinning a mere *supporting* approach towards what is sounding, but as an element of the interacting approach revealing new aspects of the objects by enabling the production of previously unheard sounds with them.



Scheme 4.10 Andrea Neumann *Inside Piano*: the soundboard of a piano is picked up by several kind of contact microphones and pick-ups and diffused by loudspeakers.

Inside Piano *by Andrea Neumann: Musical instruments and contact microphones*

Contact microphones transform ordinary objects into potential musical sound producers owing to the colour they add to the sound sources when used for amplification. Just as everyday objects experience a dramatic change in their sonic nature as soon as a resonant body is added to them through amplification, it is logical that a conventional musical instrument itself also changes as soon as amplification is added. I mentioned already in Chapter 2 that the *supporting* approach did not function as transparent as it theoretically should, taking into consideration, for example, the fact that the construction of the (electric) guitar changed completely once amplification was added. A good example of a change in a conventional instrument owing to the use of contact microphones is the work of Andrea Neumann* (Figure 4.4). She is involved with experimental piano techniques, mainly on the inner parts of a grand piano, and amplifying these actions with contact microphones. Over a period of years she discovered that the use of contact microphones changes the sound of the piano extensively, functioning as a kind of soundboard; the physical build of the grand piano was not even suitable for her way of performing and thus no longer necessary. As a

Figure 4.4 Some microphones placed on the *Inside Piano* of Andrea Neumann. From left to right: one Schertler microphone is placed on the sounding board, one taped on the strings. The Dean Marclay guitar pickup is placed on the strings. © Andrea Neumann. Photo by Andrea Neumann.

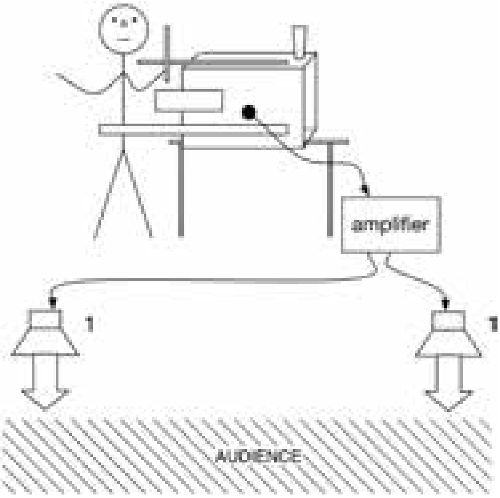
result, a special piano was designed for her by Bernd Bittmann, much lighter, without any keys or legs. Neumann developed a very elaborated amplification system for this piano. Two different contact microphones (an AKG C411 for a 'natural' amplification, as Neumann describes, and a Schertler Dyn-B for more volume and warmth in the bass register) are picking up the vibrations of the soundboard, two other contact microphones (both AKG C411 as well) are used for picking up a shelf, which was originally built only as a place for keeping the piano preparations when they were not needed. A mobile guitar pick-up (Dean Marclay) is used for amplifying all kind of small metal objects as well as creating an acoustic feedback loop by placing it on the low strings and turning up the volume. Neumann underlines that by using these different microphones she wishes to discover the many different sound characteristics of the instrument. The microphones influence what sounds she discovers on her instrument and are therefore an essential part of her set-up. She composes with different sound colours, by exchanging which microphone is emitted through the loudspeaker, having a large palette of possible combinations of these five microphones as well as the possibility to emit their sounds at different places in the stereo panorama. In this way, the same sound source can be projected in different versions. She compares her use of microphones with differently coloured glasses, or with five people all reporting in a different way about the same event (Neumann 2013). As she suggests:

> A soft scraping noise – created by moving a small metal plate on the guitar pick-up – can be emitted through the left loudspeaker. At the same time an up and down vibrating fork between the strings creates quite high metallic sounds, amplified by the AKG on the soundboard through both loudspeakers, and the sound of a small propellor amplified through the AKG beneath the shelf is diffused by the right loudspeaker.[14]

In Neumann's performances the grand piano has been changed into a different instrument which can only function properly by *interacting* with microphones in order to obtain a specific sounding result. Elements of the piano which would not normally emit much sound in themselves become audible in this instrumental set-up. What is resisting to sound in a common grand piano might be resonating here and become an essential part of the instrument. The microphones are not fixed at a specific spot, but can be adapted anew between and even during performances. This new instrument focuses mainly on producing many different sonic qualities, in contrary to the conventional grand piano, which is built to produce the same sonic quality but at eighty-eight different pitches.

Apple Box Double *by Pauline Oliveros and* Shozyg *by Hugh Davies: New instruments through amplification*

Many composers and musicians also employ contact microphones for another purpose: developing new instruments from scratch instead of transforming conventional ones. Richard Lerman* regularly uses contact microphones in his works and even amplifies bicycles with them in his piece 'Travelon Gamelon' (1977). In her performance *The Washers* (2013), Hanna Hartman* amplifies thirty-three metal rods with the help of three contact microphones. The *Apple Box* pieces (1965) by Pauline Oliveros* (Scheme 4.11) all use, as the titles indicate, wooden boxes in which apples have been stored, and contact microphones to amplify them. These apple boxes were literally everyday objects for Oliveros, since she used them to furnish her home. She has used them as resonators for all kinds of objects (Duckworth 1999, 171). Every apple box is prepared with various objects. Each player decides what kind of objects he or she will use (Bernstein and Payne 2008, 89–90). In a performance in 2004



Scheme 4.11 Pauline Oliveros *Apple Box*: a contact microphone is attached to an apple box and amplified through loudspeakers. The performer is playing objects attached to the apple box.

of *Apple Box Double* (1965), Oliveros improvises together with Seth Cluett. They attached pieces of wood and metal to their apple boxes and use glasses, cups, bows, metal chains and several other objects to play them. The material played will always sound via the resonance properties of the apple box, since the contact microphone is attached to it. The apple box together with its contact microphones functions as a kind of filter, amplifier and reverb, giving the different types of material a similar sound colour, resembling, in effect, the resonance body of an instrument, and producing a unity in sound colour similar to that achieved by an instrument, emphasized by the use of contact microphones or electromagnetic pickups (similar to the ones used in the Neo Bechstein, or in electric guitars) for amplification. Whereas Oliveros's apple boxes still convey an improvisatory and quotidian quality (although much less than Maly's coffee-making or the aforementioned pieces by Cage), more elaborate musical instruments have been invented by other composers. Hugh Davies, for example, created some very refined instruments, such as his *Shozyg* (1968), based on amplification with contact microphones and other close miking technologies, such as magnetic pickups (Figure 4.5). Davies often uses two or more different types of microphones, with differing frequency responses, since this offers the possibility of filtering the vibrations of the same object in different ways (Davies 2001, 59). The *Shozyg* is built on the cover of the final volume of an encyclopaedia out of which all the pages have been taken. Since the original encyclopaedia volume covered everything from 'shoal' to 'zygote', 'sho zyg' was printed on its spine. Davies decided to use this as the name for his instrument. Inside the cover he glued objects, such as a furniture castor, a 3D postcard and a small spring. The objects in the hard cover were amplified by means of two pickups, and the objects are isolated

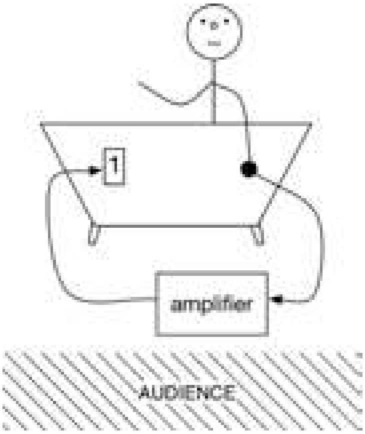
Figure 4.5 The outside and inside of the *Shozyg* by Hugh Davies. © Hugh Davies. Photo by Science Museum/Science & Society Picture Library.

from each other by being placed on two isles of felt. Once these were plugged into a stereo amplifier, the instrument was ready for use. Upon finishing, the volume just needed to be unplugged and closed again, and it was ready for transportation. From a contemporary perspective, it could definitely be associated with a laptop performance *avant la lettre* (Mooney 2015).

The multiple ways of inventing music performance through the use of contact microphones – making music out of everyday life actions (Maly), transforming conventional instruments (Neumann) or developing new instruments (Oliveros and Davies) – reveal that these set-ups can be seen as one integral sound system or, in other words, as a musical instrument. In contrary to the acoustic feedback set-up systems mentioned at the beginning of this chapter, these musical instruments consist of much more than a microphone and a loudspeaker, comprising a system which, in its totality, exhibits properties comparable to a musical instrument, with loudspeaker and microphone as interdependent components. A clear *interaction* takes place, but microphone and loudspeaker seem to be more at the edges of these interactions: although the instruments by Neumann, Oliveros and Davies could not exist without microphone and loudspeaker technology, the microphone and loudspeaker function no more extensively than as a resonating body for the objects played. Whereas the line of amplification in *Mikrophonie I* would constantly take on different forms, these last-mentioned examples could be described as having a line of amplification which, despite various curves and twists, essentially remains the same line during the whole piece. The microphones and loudspeakers are important parts of these instruments, but *interaction* with them does not differ greatly from that with conventional musical instruments. When Davies played his *Shozyg*, his movements are identified as needed for making this music instead of being related to everyday movements, whether executed by the performer, as in Maly's coffee-making, or by the audience, when playing with Lockwood's Sound Ball. There is also a clear interaction between movements and sounding results, similar to conventional performance practice, and contrary to *Pendulum Music*, for example, during which the active part of the performers is limited to starting the process. The *Shozyg* is furthermore a tangible instrument, unlike the other set-up by Davies for the acoustic feedback piece *Quintet*. Neither are there any unexpected sound characteristics revealed, since the construction of *Shozyg* is of such complexity – and the audience most likely has very little prior knowledge of the sonic characteristics of many of its parts – that there are no direct expectations regarding their sound, as would be the case with the tam-tam in *Mikrophonie I* or the everyday actions as in *0'00"*. It is primarily by reason of this last element that a *Shozyg* performance differs from performances with conventional instruments. Most of the audience attending a violin recital will probably be acquainted with the instrument, whereas an important element of a *Shozyg* performance is the discovery of the sonic possibilities of this uncommon instrument. This is evidenced by the use of a close-up video projection of the interaction between Davies and the *Shozyg* during performances, so the audience can assign his movements to the sonic outcomes.

Nodalings *by Nicolas Collins: Acoustic feedback through objects*

Attaching a contact microphone to an object, as in the *Shozyg*, could be interpreted as an enlargement of the diaphragm of the contact microphone. The diaphragm is prepared with an object, whether a coffee machine, an apple box or the frame of a piano. This diaphragm of the microphone could be extended to such an extent that it touches the diaphragm of the loudspeaker, which would in this way share its diaphragm with the contact microphone. The loudspeaker used for this purpose possesses no diaphragm of its own. A common name for such a loudspeaker is 'tactile transducer' since it drives or shakes other bodies by being physically connected to this object.[15] The result of turning up the volume in this set-up would be similar to those arising from the acoustic feedback set-up, where there was air between microphone and loudspeaker. The microphone picks up the vibration of an object, and these vibrations are amplified and sent back through the loudspeakers attached to the same object. What happened through air is now happening through a solid material: acoustic feedback becomes audible, filtered this time not by the performance space and the distance between loudspeaker and microphone but by the object the loudspeaker and microphone are connected to. Nicolas Collins* describes this kind of feedback possibility in his score *Nodalings* (1974) (Scheme 4.12). This score is written for either acoustic feedback through the air or acoustic feedback through objects, but I will focus here only on the feedback produced through objects. During a performance of this piece, various sonic representations are created of the characteristics of an object through the process of moving microphone and loudspeaker to different positions and in this way creating different feedback sounds. The objects proposed by Collins are as divers as a bathtub, a rock, a tree or a balloon. The only parameter that is modified during this piece is the amount of *material* between driver and microphone, resulting in what Collins terms a



Scheme 4.12 Nicolas Collins *Nodalings*: a contact microphone picks up vibrations caused by a tactile transducer. Acoustic feedback through a solid object occurs.

sonic 'topography' of the object (Collins 1974, 1). 'Feedback conveniently mapped the acoustical characteristics of any space (its resonant frequencies, reverberation time, frequency balance) into a sonic portrait […]' (Collins 2002, 6).

Contrary to acoustic feedback through air, which has been used extensively by many artists and which has resulted in performances with extensive and varied movement techniques for influencing the sound, the use of acoustic feedback through solid material results primarily in stationary installations. This kind of feedback has been more popular in sound installations in which no performer movements are required. Active performing with a solid object feedback set-up would imply either changing the position of microphones and loudspeakers or altering the physical conditions of the solid object. To adjust contact microphone positions is quite difficult, since the loudspeaker and microphone must be attached firmly – screwed, clamped or glued onto the object – for optimal vibratory transmission. Likewise, the physical condition of an object cannot be easily modified. For these reasons, feedback through a solid object has been used more extensively in sound installations, the installation *Schlingen* (2006) by Andre Bartetzki being one example. In this installation a big feedback set-up is built by placing contact microphones and tactile transducers on metal sheets and connecting them to each other.

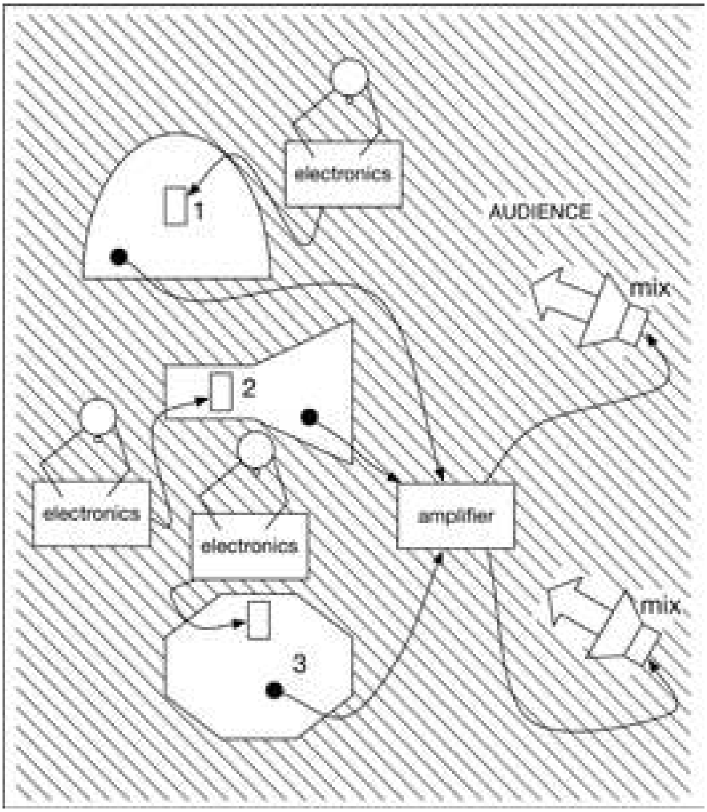
The set-up devised by Collins is very similar to that devised by Davies for *Quintet*, discussed at the beginning of this chapter, designed to produce all sounds by itself, without adding any sounds related to an object or action outside of the feedback set-up. As Collins demands in the score: 'Avoid intentionally producing any noise other than the feedback – if the movement of a contact mic along a surface produces a noticeable scraping sound, lift it to move it; raise and replace it as quietly as possible' (Collins 1974, 2). The big difference lies in the *materiality* of the musical instrument. In *Nodalings*, the musical instrument is a perceptible object. Unlike the microphones in *Quintet*, it has a clear location in the performance space and can be touched. Instead of playing the instrument by means of *movements* in the air, this time the amount of *material* in between microphone and loudspeaker is the main parameter. The line of amplification not only provides a start and end point for the sound but also serves to create distance between the sounding object and the audience. In *Quintet*, the audience is seated in the middle, and the performers as well as the microphones and loudspeakers are placed around the audience. There is no central point of focus for the performance, since the instrument cannot be localized; the instrument is everywhere, and the audience is situated 'inside' this musical instrument. In *Pendulum Music*, the set-up is limited to a more stage-like situation, with the three pairs of microphones and loudspeakers serving as the main focus. The audience no longer sits in the middle of the performance, but in front, facing it. In the pieces that follow, the object used to generate input for the microphone is also the site where the shaping of the sound begins. All pieces that use amplification with the help of contact microphones exhibit a clear start and end point in the sound-shaping process. Since the audience is always confronted with the end points (the sound emitted by the loudspeakers in the performance space), they are placed 'outside' the musical instrument. In *Nodalings*, the line of amplification is closed again into a circle through the act of connecting loudspeaker and microphone to the same material. The distance from the audience remains, however, since the audience is situated 'outside' this musical instrument. The circle of feedback takes place this time within an object instead of in the whole performance space.

Using a solid material as diaphragm for a microphone and loudspeaker is closely related to the tuning fork oscillator and the Dieckmann-piano system, in which a piano string is involved in the functioning of both microphone and loudspeaker (see Chapter 3). When a microphone and loudspeaker are connected to the same object, this material serves both as a sound shaper and as a sound emitter. Characteristics of these objects that serve as diaphragms evidently are not aligned with the ideal characteristics of diaphragms used for approaches that form part of the tympanic principle (*reproducing*, *supporting* and *generating*), since the loudspeakers used for the latter principle should be in general transparent transmitters of sound. With feedback through an object, I am once again returned to the tuning fork principle. The material shapes and radiates the sound.

Rainforest *by David Tudor: Every loudspeaker a different voice*

Probably one of the most important questions regarding music which uses the *material* of the microphone and loudspeaker diaphragm as a starting point is how the audience perceives this *material*. When listening to a sounding object like a violin, a piano or metal bowl, we have some awareness of the nature of the material that is involved in producing the sound as well as the technique used to produce the sound, owing to our experiences with sound. We have learned how strokes on metal, a bowed string or a breaking glass sound. What makes recognizing sounds even easier during musical performances with conventional musical instruments is the possibility to also see what causes the sound. As discussed in Chapter 2, any sound can, theoretically, be transmitted by loudspeakers. There is no sonic expectation raised through the sight of a loudspeaker, contrary to the sonic expectations the visual appearance of, for example, a piano is causing. In the pieces discussed so far which use *material* as the main parameter of variation, actions of the performers often reveal relationships between material and sound. Contact microphones are used to pick up the vibrations of the material and emit them through the loudspeakers. But what if there is no performer bringing the material into vibration? How can we hear that it is the material which is influencing the sound, when a loudspeaker can, in theory at least, reproduce every sound?

Acoustic feedback through objects thus forms what one might term a closed circle, initiated at some distance from the audience. To bring this musical instrument closer to the audience again, as was the case in Davies' *Quintet*, a solution might be to open the circle. This is done in the project *Rainforest*[16] by David Tudor* (Scheme 4.13). A line is developed which extends beyond the feedback circle. The pieces by Lucier, Wellmer and Stockhausen opened the feedback circle through the act of inserting a sound source in between microphone and loudspeaker. In *Rainforest*, the connection between tactile transducer and contact microphone, instead of the connection through air between microphone and loudspeaker, is opened. Rather than adding a sound source in the



Scheme 4.13 David Tudor *Rainforest*: an electronic signal is emitted by a tactile transducer. The tactile transducer brings an object into vibration. These vibrations are picked up by a contact microphone and diffused by an 'ordinary' loudspeaker.

performance space, Tudor constructs elements of variation in the electrical signal and opens the feedback circle between microphone and loudspeaker instead of between loudspeaker and microphone. Tactile transducers have become popular in music during the last decade. Sabrina Schroeder*, for example, has composed several pieces with drums and tactile transducers, in which she create sounds by playing the drums through the tactile transducers.

Rainforest is based on *interaction* between loudspeakers and all kinds of *material*. Tudor describes the aim of his project *Rainforest* in the following words: '[…] what I would like to do would be to make an orchestra of loudspeakers all having different "voices" which would all receive a common input' (Fullemann and Tudor 1984). Developing loudspeakers which are as unique as any musical instrument was one of his main aims for this project (Driscoll and Rogalsky 2004, 26). To achieve this he attaches all kind of different objects to the tactile transducers, resulting in one-of-a-kind loudspeaker sculptures. *Rainforest* performances are the creative sound-generating result of workshops in which many artists participate. Every participant has made his or her own loudspeaker sculpture during a preceding workshop. The sculpture should reveal its resonating characteristics, made audible through the vibrations of the tactile transducers. Once again, the various objects used in the loudspeaker sculptures filter the sound. Certain frequencies are radiated much more strongly, and others much more softly, by the sculpture in response to the tactile transducers. John Driscoll*, who took part in the first performance of *Rainforest IV* in 1973, describes this influence by the sculpture on the sound: 'The resonance nodes of the sculptural speaker contribute to what is heard as much as do the original sounds and in some cases influences the result even more. It is possible to input a sound that is unrecognizable coming out of the sculpture' (Driscoll and Rogalsky 2004, 29). Regarding the input sound, everything, with the exception of pre-recorded material, is allowed. The tactile transducer's input is no longer connected to the microphone input, as is the case in *Nodalings*, but to an electrical signal, which is shaped by the participating artists. Material for loudspeaker sculptures can be almost anything, and consisted of objects found by trial and error in a search for interesting resonances.

The search for these kinds of resonances through the objects has been described in detail by artist Bill Viola, who took part in *Rainforest* workshops and performances

Figure 4.6 Sabrina Schroeder attaches a tactile transducer to a drum. The clear fishing lines are used for keeping the transducer in place during performance. © Sabrina Schroeder. Photo by Phillip Schulze.

as a student. David Tudor introduced the basic principles of the piece to the students during the workshop. Tudor used a simple sine wave oscillator that emitted a sine wave through the loudspeaker without diaphragm. He began with a very low frequency and performed one long glissando increasing in frequency. The object excited by this loudspeaker would respond to certain frequencies by vibrating and rattling, and the result was a much more complex sound, containing many more frequencies than the sole, initiating, sine wave. At other frequencies, however, the object would react by simply reproducing the sine wave (Viola 2004, 48). What Tudor revealed with this simple experiment are the nonlinear response potentials of the objects used and the wide disparity in vibratory reaction, according to the physical characteristics of the objects. Every object will evidently react differently to the oscillator frequencies, since they all have differing resonating properties. To discover the sounds that were 'asked' for by a certain object, many experiments with different kind of audio signals were conducted by the *Rainforest* participants, until they came across the sounds that they felt suited the object best. The participants often looked for atypical ways of connecting the loudspeakers to the object in order to cause unexpected resonances. One example of this is the connection of two out-of-phase loudspeaker coils to a single object, thus engendering peculiar vibrational patterns (Driscoll and Rogalsky 2004, 28).

Examples of material used during a performance in 1973 are a metal bedspring, a huge wine barrel and a Styrofoam box (Driscoll and Rogalsky 2004, 29). These loudspeaker sculptures were amplified using contact microphones. The signal coming from the contact microphones is amplified through transparent loudspeakers, that is to say, loudspeakers that would add the least colouring possible (thus functioning according to the *supporting* approach). The performance of *Rainforest* includes therefore not only the sounding sculptures, but sonic images of these vibrating sculptures as well, emitted by loudspeakers from another area of the performance space. As Tudor formulates,

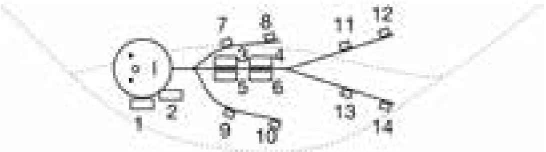
> the purpose of the contact mike is to take the resonant frequencies which you hear at best very close to the sounding object; to take those into an ordinary loudspeaker which you can consider not as auxiliary but as enhancement. What that does when you establish the proper tonal balance is that you've got a reflection of the sound which you can distance in space. (Fullemann and Tudor 1984)

In this manner, *Rainforest* uses both a point of radiation (the loudspeakers prepared with objects) and a line of amplification (from the contact microphones picking up the vibrations of the loudspeaker-objects to the transparent loudspeakers). Tudor professes to search for loudspeaker sculptures which are as unique as any musical instrument. Their unique sound should not be forced upon them by the performer or instrument builder, as is the case for conventional instruments; the loudspeaker sculptures should 'themselves decide' what sound they 'want to' produce. Tudor is not only giving the loudspeakers their own voice, but also seeking to give them the freedom to discover this voice for themselves. The loudspeakers might be thought of as musicians, playing the objects and finding the resonances of the objects. Tudor wants the objects to reveal their own resonant characteristics, rather than to be used as instruments to be played manually. As he said in an interview in 1972, one year before the big *Rainforest IV* performance: 'I try to find out what's there – not to make it do what I want, but to release what's there. The object should teach you what it wants to hear' (Collins 2004, 1). The human performer therefore no longer functions as an interpreter, but much more as a listener who carefully attends to what the object can teach him or her.

Rainforest is an example of a piece in which the material is not brought into vibration through direct contact between performer and objects, as was the case, for example, with the performances by Maly, Neumann or Oliveros. Instead of the performer, the audience will be in closer contact with the loudspeaker-objects during a performance. First of all, since the audience is allowed to walk through the performance space, they will be able to trace the different sounds to the different loudspeaker sculptures. During a performance the audience is encouraged to interact directly with the loudspeaker sculptures. They are allowed to walk among and to interact physically with the sculptures by placing their ear against them, taking them in their hands, using a stethoscope or even biting into them (Driscoll and Rogalsky 2004, 28). The tactile sense becomes an important part of the perception of this performance. Instead of only hearing the sounds, with the membrane of the ears as interface, the vibrations are now perceived as well by the skin and teeth as well. Owing to the direct tactile perception of the sound vibrations, a kind of listening independent of any use of the tympanic membrane of the ear can take place.

Aptium *by Lynn Pook, and Merzbow: The audible becomes feelable*

The audience members in *Rainforest* become prolongations of the loudspeaker-instrument, since by touching it they alter the vibrations of these objects. Lynn Pook* has utilized this physical connection between loudspeakers and audience members in an even more radical manner. In her work, the vibrations of loudspeakers are no longer communicated in the form of air pressure waves at all, but rather as mechanical vibrations on the bodies of the audience members. Due to bone conduction, the vibrations are transmitted directly to the inner ear. Pook seeks to reduce the distance between the sound of the performance and the body of the audience. In her work *Aptium* (2004), the music performance is given for one audience member only (Scheme 4.14). The visitor is invited to lie in a hammock equipped with fourteen small



Scheme 4.14 Lynn Pook *Aptium*: small loudspeakers are attached at several points of the body of the audience member. An electro-acoustic composition is diffused through the loudspeakers, perceptible for the audience member through bone conduction.

tactile transducers. The transducers in the hammock are in contact with the back of the audience member, and several other tactile transducers are attached to places of the body well suited for bone conduction, such as elbows and knees. The hammock isolates the body and the transducers from the floor, preventing dampening of the vibrations by the floor. The vibrations of the in total fourteen loudspeakers are only audible for this specific audience member. The connection between transducer and body is uninterrupted, since the loudspeaker literally touches the listening body (Figure 4.7). Pook calls this an audio-tactile experience (Pook 2004, n.p.). To be able to completely concentrate on the vibrations through the bones, the person is blindfolded and the ears are closed with earplugs or earmuffs.

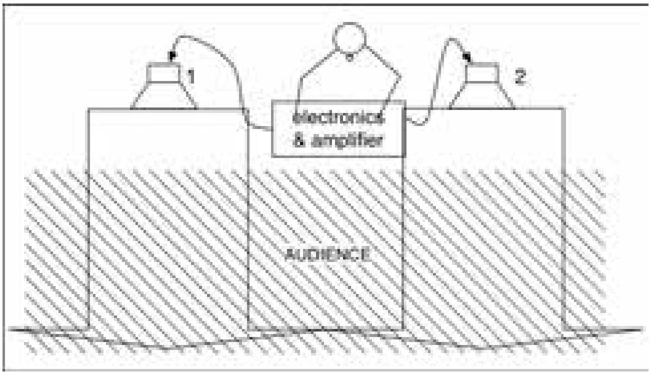
Similar to the way a contact microphone picks up sound, listening through bone conduction is very localized: the knee can receive the vibrations for a certain sound, whereas at the same time the elbow is excited by completely different frequencies. All these frequencies become audible for the audience member through bone conduction to the skull, which transfers the vibrations directly to the inner ear. The same sound would be conveyed differently from another part of the body, since the different bones resonate at different frequencies. The conceptualization of human listening, with the ear as its primary organ, has served as the model for the *tympanic principle*, as I argued in the last chapter. But as demonstrated in *Aptium*, the ear itself is already 'tuned': our tympanic membrane and all other parts of the ear – the outer ear of every human being is shaped uniquely, for example – do not resonate linearly at all frequencies. For this reason, the ear itself cannot be seen as the perfect embodiment of the tympanic

Figure 4.7 Fourteen small tactile transducers are attached to the body of the audience member during *Aptium* by Lynn Pook. © Lynn Pook. Photo by Lynn Pook.

principle! The listening human body is unable to perceive anything other than its own vibrations, whether these are produced by the tympanic membrane of the ear or by bone conduction through the whole body. In this performance by Pook, the audience member might be regarded as taking the place of the object attached to the loudspeaker in *Rainforest*. The audience member has to touch the musical instrument, and in a way seems to even become a part of the musical instrument, in order to experience the musical performance.

Feeling sound vibrations, as in *Aptium*, is also experienced during rock concerts, due to the very high amplification of bass frequencies, and can be encountered in an extreme form in noise music. The music of Merzbow* is not only audible, but tangible as well. Staging performances in small spaces with enormous sound volumes often creates resonances in low frequencies, since their length fit well in the performance room (Hegarty 2007, 142) (Scheme 4.15). The performance space itself thus functions as a large resonator. These low frequencies are amplified to such an extent that the movements made by the diaphragms of the loudspeakers produce airwaves powerful enough to cause the clothes of the audience to vibrate. These vibrations are tangible to the audience's bodies and create the impression of engaging sound in fluid form. The audience experiences what they express as being 'really touched' by the sound (Friedl 2002, 30). The bodies of audience members are put into vibration, this time not through direct physical contact with the resonating material but through very powerful air pressure waves. The material exposed in these kinds of performances is neither the sonic qualities of physical objects (as with Tudor's *Rainforest* performances) nor the conductive properties of the body of the audience member herself (as in Pook's *Aptium*) but the *material* of sound itself: air pressure waves, often only perceptible by the ear, now become tangible. The loudspeaker reveals its own function: causing air pressure waves.

The pieces by Tudor, Pook and Merzbow reveal that sound perception itself is related not only to the sense of hearing but is also connected directly to our tactile sense. The *material* aspect of sound is discovered by the experience that, when we are listening,



Scheme 4.15 Merzbow: due to performing with very high volume levels and low frequencies, the air pressure waves become feelable for the audience.

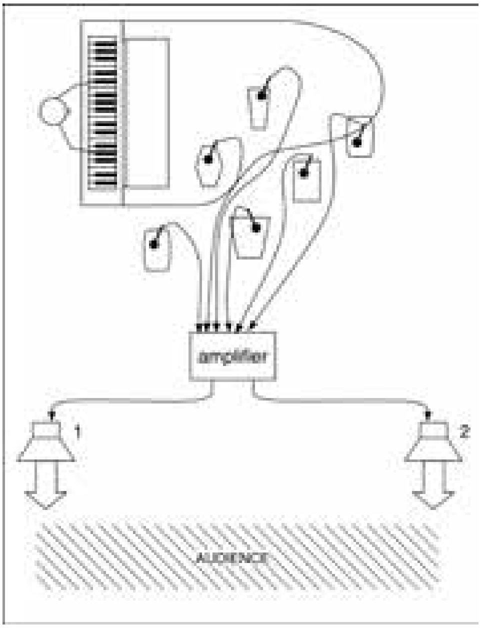
our whole body is resonating. The bodies of the audience members themselves are manipulated directly by the loudspeaker sound. Whereas musicians are commonly the only ones who touch their instruments, the audience is now allowed or even forced to be touched by the sound, which reveals itself through body parts other than the ear membrane. Also based on points of radiation, these pieces differ from *Speaker Swinging* by Monahan and *Three Short Stories and an Apotheosis* by Lockwood owing to their focus on the audience's body. There is no change in distance, neither is there any movement of the sound-emitting object. Instead of treating the musical instrument as a limited object, these set-ups have no clear borders between musical instruments and audience members. In the works by Monahan and Lockwood, the locations of sound emission are constantly changing due to the motion of the loudspeakers; because of the audience's capability of localizing the sound-producing object in the performing space, the object-character of the loudspeakers used is underlined. The audience experiences these loudspeakers as being points in space, outside of their own body. The pieces by Tudor (when the sculptures are actually touched by the audience), Merzbow and, especially, Pook are characterized by transferring the sound wave vibrations onto the body of the audience. The skin of the human body seems to become itself a membrane that is brought to vibration. Contrary to set-ups using contact microphones or moving loudspeakers, the audience does not remain outside the set-up; neither are they located inside the set-up. Instead, the audience is an essential part of the set-up.

Space

The Merzbow performance shows that sound touches objects, in his case human bodies, at a distance. Sound itself is influenced by the human bodies perceiving the sound as well as by all other material the sound waves are meeting. Musicians notice the acoustic difference between rehearsing in an empty concert hall and performing in the same hall filled with the sound-absorbing bodies of the audience members. Sound waves are travelling through space and are modified by this space. There is a constant interaction between microphones and loudspeakers, the sound waves they emit and pick up, and the space they are placed in. *Space* is therefore the third parameter, after *movement* and *material*, that I consider here.

Music for piano with amplified sonorous vessels *by Alvin Lucier: Interaction between microphones and small spaces*

In the piece *Music for piano with amplified sonorous vessels* (1990), Alvin Lucier puts microphones into different vessels, such as wine glasses, flower vases, big bottles, seashells and bamboo cups (Scheme 4.16). These objects are placed close to or inside a grand piano so they can pick up the sounds that are played on it. These vessels resonate at certain frequencies according to their shape (similarly to the resonance frequencies heard when blowing on a bottle). These resonance frequencies are picked up by microphones that are inserted into the vessels and subsequently amplified through



Scheme 4.16 Alvin Lucier *Music for piano with amplified sonorous vessels*: the resonance of the piano sound in different kind of vessels is picked up by microphones. The signal of these microphones is radiated through loudspeakers.

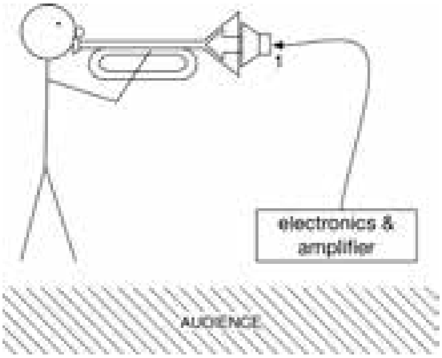
loudspeakers. Every microphone renders a different sound of the piano, coloured by the resonant properties of its vessel. The vessels often resonate at slightly different pitches than the frequencies played by the piano. This creates audible beats resulting from the interference between the amplified slightly out of tune frequencies from the vessels and the piano tones (Lucier, Kleeb and Dahinden 1997, n.p.). Now the various simultaneously resonating bodies become audible. Normally the strings of a piano are amplified by means of the instrument's own resonating soundboard; with this set-up the multiple vessels take over the function of a soundboard, and an unusual instrument is created with one point of excitation, namely the piano string, which resonates through several small bodies (the vessels).

Changing the sound of a piano is often accomplished by placing all kinds of so-called preparations, such as screws, in between the strings. This piece by Lucier should not, however, be considered a composition for piano with some (quite elaborate) preparation. The main set-up is formed by the combination of the piano with the microphones in the vessels – which may be viewed as small reverberating spaces – functioning as resonators. The microphones in the vessels here fulfil a function similar to that of the resonant body of conventional musical instruments: they are clearly shaping the sound, since the audience knows how a 'normal' piano sounds and will recognize the resonances added through the amplification of vessel frequencies by microphones.

This piece is based on lines of amplification, which all begin from the same origin, namely the piano, but all seem to end at, and thus emit sound from, another location. These lines are no longer attached to the material, either by contact microphones or by tactile transducers. The microphones are prepared with objects, similarly to the loudspeakers of *Rainforest*. This preparation is not accomplished by connecting objects to the diaphragm, but by placing the microphones inside different objects, vessels in this case. It is not the vibrations of the *material* of the vessels that are picked up by the microphones, but the vibrations of the air in the vessels, of the *space* inside. Whereas in the pieces by Tudor, Pook and Merzbow the body of the audience formed part of the material set-up, in *Music for piano with amplified sonorous vessels* the audience is outside once again. The sounds interact with different spaces, but the audience perceives these spaces from a position outside of the set-up itself.

Loudspeakers in brass instruments and focused loudspeakers: Interaction between loudspeakers and small spaces

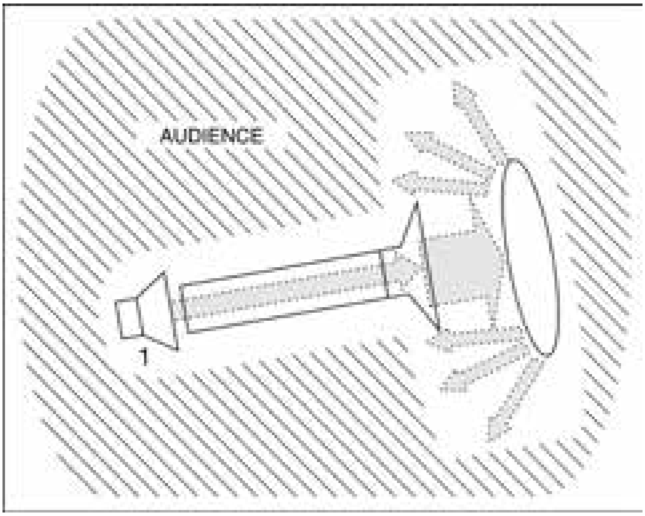
In a comparable manner to Lucier placing microphones inside vessels, loudspeakers have also been put in small spaces to evoke colourations of the sound they emit. It has become common practice for brass players, for example trumpet player Birgit Ulher or trombonist Hilary Jeffery, to use a loudspeaker to project sound inside the bell of their instruments (Scheme 4.17). Instead of a mute, which changes the sound colour of the instrument, a small loudspeaker is placed inside the bell, and the sound emitted by the loudspeaker is coloured by the resonances of the construction of the brass instrument. Moving the loudspeaker in and out of the bell again changes the colour of the sound coming from the loudspeaker. An early example of this kind of playing technique can be found in the piece *Acustica – für experimentelle Klangerzeuger und Lautsprecher* (1968–1970) by Mauricio Kagel* (Kagel 1970). Both a trumpet and a trombone use so-called loudspeaker mutes.[17] When a loudspeaker is used as a mute for brass



Scheme 4.17 Loudspeakers in brass instruments: a small loudspeaker is used as a mute for a brass instrument. By moving the mute the sound diffused by both trumpet and loudspeaker is modified.

instruments, in this set-up the loudspeaker could be regarded as a point of radiation. In this case, in contrast to the other examples with conventional musical instruments I described earlier (Wellmer's *Green Piece*, Stockhausen's *Mikrophonie I*, Neumann's *Inside Piano* and Lucier's *Music for piano with amplified sonorous vessels*), the sound of both musical instrument and loudspeaker are altered by moving the loudspeaker in and out of the bell. In all other pieces the musical instrument was the starting point of the line, ending at a loudspeaker emitting the sound. As a result of these necessarily synchronous changes, the sound emitted by the loudspeaker and the sound of the trumpet are strongly connected to each other: when the loudspeaker sound is muted, the trumpet sound will be muted as well.

Another way of influencing the sound emitted by loudspeakers was researched by the group *Composers Inside Electronics* in 1977 (Driscoll et al. 2012) (Scheme 4.18). The participating group members, who had met at a workshop on David Tudor's *Rainforest,* were Tudor himself, Martin Kalve, Ralph Jones and John Driscoll*. Their aim was to develop loudspeaker objects which would have maximum directional characteristics, and which therefore would be easily localizable in space. Instead of using the kind of phantom sources between the loudspeakers which are characteristic of stereophonic technology, the aim was to make distinguishable sound sources out of the loudspeakers themselves. By mounting all kinds of objects like horns, plates or parabolic structures around the loudspeaker, the sound is projected in specific direction instead of being emitted in all directions. Depending on your position as an audience member, you will hear different reflections of the sound waves. These kind of set-ups are especially effective when the audience can approach the object very closely, since then they can search themselves for the different spatial diffusions of the sound. These will be lost



Scheme 4.18 *Composers Inside Electronics* focused loudspeaker research: the radiation characteristics of loudspeakers are modified by adding objects like horns, tubes and lenses.

as soon as the audience member is further away of the loudspeaker-object. Since all of the collaborators on this project had worked on *Rainforest* it is no surprise that these set-ups look like a deconstructed *Rainforest* loudspeaker sculpture. The objects used to modify the sound, such as horns and tubes, are related to the construction of acoustical wind instruments. These forms are advantageous as resonant spaces for air pressure waves. Driscoll in particular continued to use these kinds of loudspeakers in his performances and installations. He developed rotating robotic loudspeaker instruments and used them, for example, in his work *Stall* (1981). He designed these loudspeakers to disperse the sound physically instead of using stereophonic technology, interacting with the space and revealing its acoustical characteristics, or as Driscoll formulates it: 'to excite acoustical spaces in a musical manner' (Driscoll 2012, 1). The focused loudspeakers are built to create each a specific spatial effect, and thus all radiating their sound differently.

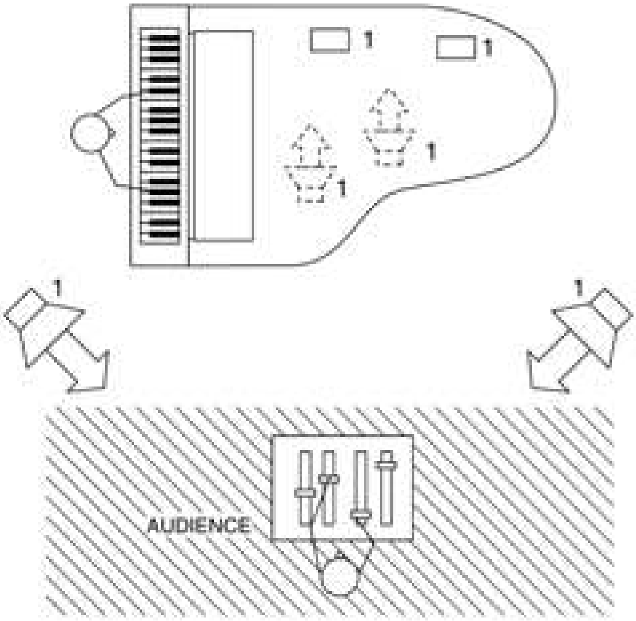
Commonly, when referring to space in relation to microphones and loudspeakers, what is intended is not so much the kinds of small spaces in the examples mentioned above (vessels, brass instruments or horns and tubes), but instead 'spatialisation' techniques which are used to diffuse sound throughout the performance space. Over the last eighty years many forms of loudspeaker-based sound spatialization have been developed, an early example of which was a concert in Berlin in 1930 where Paul Hindemith's *7 Triostücke für 3 Trautonien* was performed with a separate loudspeaker for each instrument, suspended in the middle of the hall above the audience. Apart from such incidental experimentation in concert with loudspeaker spatialization in the first half of the twentieth century, the movie industry also developed several sound systems which could project sound in space, one of the first being Fantasound developed for the movie *Fantasia* (1940) by Walt Disney, which was intended to function as an orchestra concert in the cinema, so that good sound quality was extremely important. The conductor Leopold Stokowski not only conducted the piece but was engaged in the production process as well. During the premiere in Broadway Theatre in New York, ninety loudspeakers were placed throughout the room to offer the possibility of projecting the sound from different directions (Kletschke 2011, 74).

Many spatialization systems using loudspeakers either focus on kinds of spatialization which could not naturally exist (this is often the case with systems like Ambisonics and Wave Field Synthesis) or try to copy known spatial sound situations (often realized with a stereophonic sound system for the living room and the 5.1 surround sound system for the cinema). These kinds of spatialization systems are consequently related to the *generating* and *reproducing* approach: the loudspeakers should be transparent, and virtual spaces which have no relationships with the loudspeakers are generated in the performance space. The spatialization in these systems takes place before the sound is emitted by the loudspeaker. There is no *interaction* between loudspeaker and performance space. On the contrary, often the loudspeakers are placed in a set-up that avoids this kind of interaction as much as possible, being placed, for example, symmetrically in a circle, all at the same distance from and directed to the audience. The air pressure waves are radiated as directly as possible towards the audience, avoiding as much as possible any influence of the performance space on the sound. The loudspeakers should *generate* or *reproduce* a spatial image in this set-up. Although these spatialization systems are very interesting and inspiring (*generating* new spatial experiences in sound especially is very challenging for composers, due to the 'inaudible' loudspeakers in those systems), I will not discuss these systems here in more detail, since they do not belong to the *interacting* approach.

.....sofferte onde serene... ***and*** **Guai ai gelidi mostri** ***by Luigi Nono: Interaction between loudspeakers and performance space***

Sounds emitted by loudspeakers may be shaped not only by small objects but also by the performance space itself. Luigi Nono* was interested in exploring the different spatial qualities of sounds, and an important element of many of his compositions is the placing of sounds in order to reveal these spatial qualities, of both the acoustic space and the sound as it changes. These changing spatial qualities in the sound should not be confused with changes in its location of the sound. Spatial changes in Nono's work are not simple sound movements, in which a sound moves from right to left or from front to back. These kinds of movements are most easily achieved without any interaction between loudspeakers and performance space, for example by means of the Ambisonics technology. Nono was very keen on placing the loudspeakers in such a way that a change in the positioning of the sound emission also meant a change in sound quality. This implies that the loudspeakers should all have a different relationship with the concert hall they are placed in, so that each loudspeaker has its own way of radiating sound. Contrary to systems that ask for transparent loudspeakers positioned in such a way in the performance space that the acoustical qualities of the space are revealed the least possible, Nono's music proposes that loudspeakers should be in dialogue with the concert hall and the acoustical qualities of the concert hall should be audible through the positioning of the loudspeakers. Many of the loudspeaker set-ups devised by Nono involve these kinds of relationships between loudspeakers and space, and all of the loudspeaker set-ups used in his work shape the final sound result.

A good example of this method is *.....sofferte onde serene...* (1976), for piano and tape (Scheme 4.19). As described in the score, two small and two large loudspeakers should be used to play the monophonic tape. The two large loudspeakers should not be pointed directly at the audience, but should first radiate their sound to the wall or ceiling of the concert hall. Instead of coming directly from the loudspeakers, the sound will seem to come from the walls and ceilings of the performance space. As described in the score by Alvise Vidolin*, who assisted at many of Nono's performances, these loudspeakers should be used to 'highlight separation and dialogue between the tape and the piano' (technical notes in the score of *.....sofferte onde serene...*, Nono 1992). The two small loudspeakers should be placed underneath or behind the piano in such a way that their sound is projected on the soundboard of the piano, causing the soundboard of the piano to resonate, and should be used for mixing the sound of the live piano playing with the sound of the tape. Decisions about where the monophonic tape signal should be sent – either towards the larger loudspeakers, towards the piano loudspeakers, or both – are made by the person playing the tape. There is no



Scheme 4.19 Luigi Nono .....*sofferte onde serene*...: the monophonic tape in this piece can be played through two loudspeakers in the hall as well as through two loudspeakers underneath the grand piano. The person at the mixing desk has to 'play' the tape by deciding through which loudspeakers the tape is sounding. Alvise Vidolin added two tactile transducers to have better frequency response for especially the high pitches.

fixed score for the sound diffusion mix, since the loudspeakers will sound differently depending on the performance space and the piano used; for this reason, sound diffusion as well as loudspeaker placement should be adapted to their characteristics. When performing .....*sofferte onde serene*... Vidolin is often inventing new set-ups for this piece. He has, for example, experimented with placing two tactile transducers on the soundboard of the piano (Figure 4.8). These tactile transducers will excite the high frequencies of the piano, which are often lacking on the recording, since it has been made in the 1970s. As Hans Peter Haller*, who collaborated intensively with Nono at the *Experimentalstudio der Heinrich-Strobel-Stiftung des Südwestfunks* in Freiburg, mentions, the published scores by Ricordi do not reflect Nono's performance practice. Haller points out that the loudspeaker should be regarded as a musical instrument, constantly interacting with the concert hall (Haller 1995a, 100). The quality changes in spatialization are audible, but there is no possibility of notating these as quantitative parameters for sound projection (Haller 1995b, 154).

In the later works by Nono, developed at the Experimentalstudio in Freiburg, the use of multiple spatial perspectives of a single sound undergoes further evolution. *Guai ai gelidi mostri* (1983) is written for flute, clarinet, tuba, two alto voices, viola,

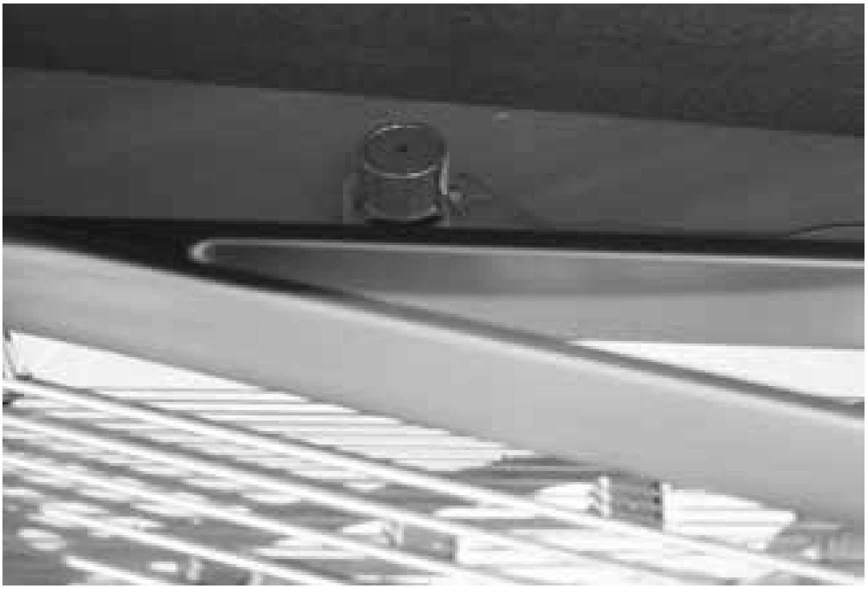
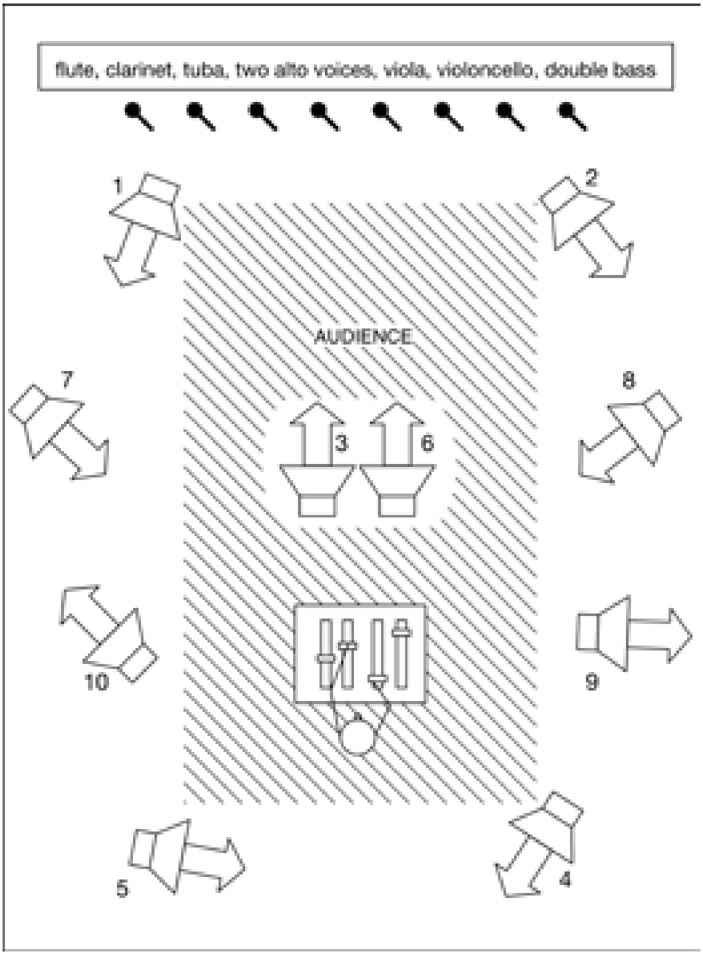


Figure 4.8 A tactile transducer is placed on the soundboard of the grand piano for a performance of*…..sofferte onde serene…* as interpreted by Alvise Vidolin. Photo by Cathy van Eck.

violoncello, double bass and live electronics and uses ten loudspeakers (Scheme 4.20). The instruments and voices on stage are played live and their sound is simultaneously diffused in the concert hall, sometimes processed by live electronics. The live electronic processing schemes made for different concerts of *Guai ai gelidi mostri* demonstrate that this processing was changed for every concert and adapted in response to these changes in sound due to the acoustics of the performance space (Vidolin 2006). Whether filters, pitch shifters or reverb were used was partially dependant on the interaction between loudspeakers and performance space. The spatialization of the sounds in a particular space, in combination with the specific placements of the loudspeakers, changed the resulting sounds.

Nono often utilizes the indirect sounds of the loudspeakers, by placing two loudspeakers above the audience and pointing towards the ceiling in *Guai ai gelidi mostri*, for example. The voices are amplified through these two loudspeakers. As Nono mentions in his score, the aim of positioning the loudspeakers in this manner is that the audience members are unable to determine where the sound is coming from (Nono 1983, 112). In preparation for a concert, Nono and his colleagues experimented for hours, searching for the right position and diffusion direction for each loudspeaker in the concert hall (Haller 2003, n.p.). Nono explicitly mentions in the score that the loudspeakers should be placed asymmetrically around the audience on different levels (Nono 1983, 112). The whole set-up of performers with their instruments,



Scheme 4.20 Luigi Nono *Guai ai gelidi mostri*: the sounds of the musical instruments on stage are processed live and diffused on ten loudspeakers in the hall. The loudspeakers are positioned in such a way, that they emit their sound often to the walls or the ceiling. In this way they interact with the acoustics of the performance space.

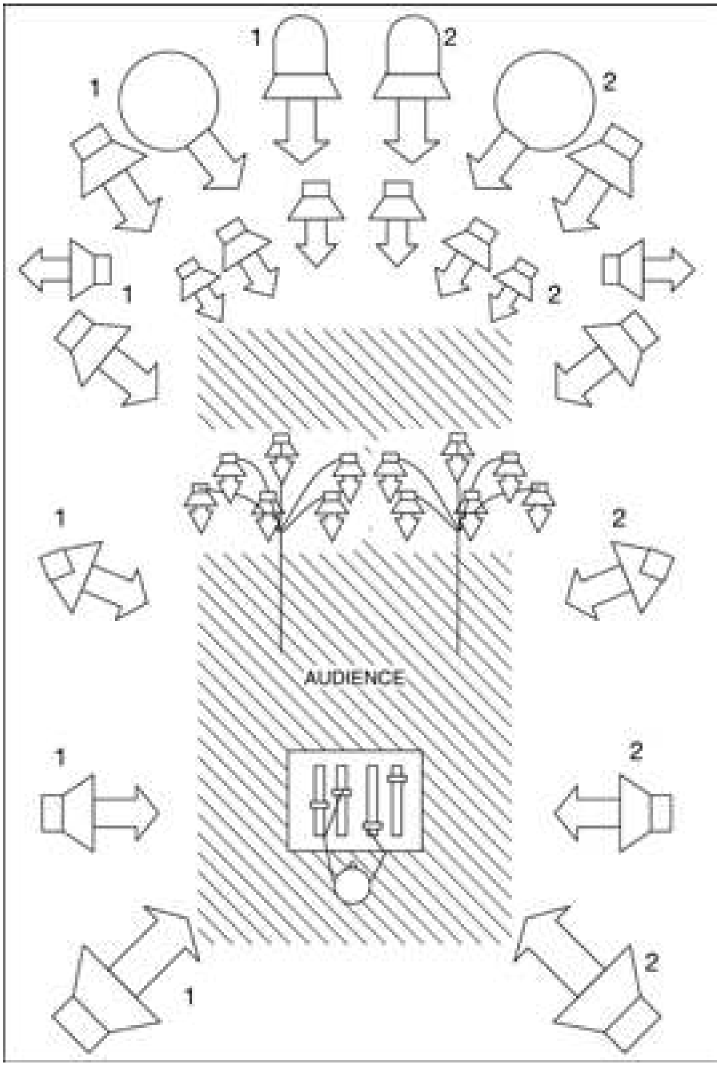
microphones, all devices for the live electronics, loudspeakers and the concert hall are part of one large musical instrument.

I would like to examine the difference between changing an element at the starting point of the line of amplification or at the end point. To investigate these differences, Nono's set-up for a piece such as *Guai ai gelidi mostri* might seem similar to *Mikrophonie I*, but the sonic result is not that similar at all, due to the different use of microphones and loudspeakers. Stockhausen makes changes close to the starting point of the line, through microphone movements, whereas Nono modifies the end of the line, through loudspeaker placement. In both cases, several sonic representations of the same instrument(s) are projected in space, altering the sonic perspective of the instrument(s). In *Mikrophonie I*, changing the distance between the microphone and the tam-tam, or between the microphone and the object which sets the tam-tam in vibration, results not only in a louder or softer sound but also in a change in the frequency spectrum (commonly called sound colour), as well as in a change in the balance of direct and indirect sound. The loudspeakers in *Guai ai gelidi mostri* modify the sound according to their place in the performance space. Changing the loudspeaker through which the sound is radiated results in a change of localization of the sound in space as well as a change of frequency spectrum. In *Mikrophonie I*, the sounds fade in and out not only in volume but also in sound colour – the sound of the tam-tam varies between sounding very close and very far away. In *Guai ai gelidi mostri*, there are modifications in sound colour, as in *Mikrophonie I*, but also in direction – the implementation of and interaction with loudspeaker positions in space results not in a variation in distance between listener and sounding object (as is the case in *Mikrophonie I*), but rather in a less hierarchical variation between different sonic presentations. The audience's sonic perspective in *Mikrophonie I* is constantly changing, approaching or retreating from the tam-tam. In *Guai ai gelidi mostri*, the distance between audience and musical instruments on stage remains the same, but the musical instruments are heard in different acoustic configurations.

Acousmonium *by François Bayle: Loudspeaker orchestras*

Over the last seventy years many other experiments, apart from the work by Nono discussed earlier, have been performed to investigate the *interaction* between loudspeakers and performance space, one of them being the so-called loudspeaker orchestras. All these orchestra's are formed, as the name already reveals, of many loudspeakers, often but not always using different types. Every loudspeaker orchestra have their own specific set-up possibilities, good overviews can be found in *Loudspeaker Orchestras. Non-Standard Multi-Loudspeaker Diffusion Systems* (Deruty 2012) and *Mehr! Kleines Handbuch des Lautsprecherorchesters* (Heiniger 2015). My focus will be on the Acousmonium, other well-known orchestras being BEAST, Cybernéphone and since 2013 also the Berliner Lautsprecherorchester. Also the full-sphere and hemisphere loudspeakers developed by Perry Cook and Dan Trueman from 1997 used in so-called laptop orchestras could be seen as belonging to this category, since they are placed close to the laptop players of the orchestra and diffuse their sound in all directions in a manner similar to conventional instruments. In Thomas Kessler's* *Utopia I* (2004) and *Utopia II* (2011), the idea of a loudspeaker orchestra and a symphony orchestra are combined, since each musician is connected to a personal live electronic set-up, containing, for example, a synthesizer, a laptop and a control foot pedal. The sound resulting from this live electronic processing is diffused through a loudspeaker, which is placed next to the musician. The orchestral musicians are thus able to control the live electronic manipulations of their own sound. Apart from the *Utopia* pieces by Kessler, all other orchestra's have in common that the same loudspeaker set-up is used for different pieces. In the other set-ups I discussed here, every set-up was specifically invented for a specific piece.

The Acousmonium is one of the first loudspeaker orchestra's and was developed by composer François Bayle* in 1974 (Scheme 4.21). This consists of dozens of different loudspeakers, often as many as eighty, arranged in the performance space



Scheme 4.21 Acousmonium: an orchestra of loudspeakers is placed in the performing space. A two-channel sound file is diffused on this system by an interpreter.

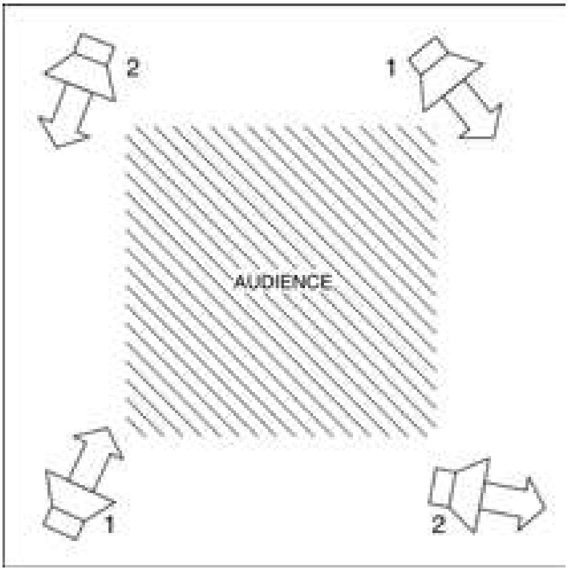
in a symmetrical set-up, so that all loudspeakers come in pairs. Earlier versions also used non-symmetrical loudspeaker placements. Many different types of loudspeakers are used for the orchestra, in contrast with, for example, Ambisonics or Wave Field Synthesis loudspeaker systems, in which all loudspeakers should be identical. The different loudspeakers comprising the Acousmonium all have their own individual characteristics, such as frequency range, amplitude range, sound dispersion pattern, and so on. There are for example special high range loudspeaker (tweeter) trees, which are often placed among the audience. Some of the loudspeakers are directed towards the audience, whilst others are pointed at the wall or the ceiling for a more indirect sound. Although the loudspeakers are distributed all around the audience, a sonic focal point is formed in front of the audience, as is traditionally the case in concert performances. Some of the loudspeakers are intended to reproduce all frequencies, whilst others are used for amplifying the bass (the subwoofers) or adding some extra reverb (such as the loudspeakers pointing towards the ceiling). The music composed for the Acousmonium is commonly in stereo format and is mixed live during the concert by moving the faders controlling the volume of the different loudspeakers. Sometimes multichannel works are performed as well with this loudspeaker orchestra. This set-up, consisting of multiple points of radiation and the person performing the mix, thus produces a changing sonic output during the performance, depending on which of these points of radiation are active. Due to the combination of just two audio tracks and many different loudspeakers, manifold possibilities for diffusing the sound in space come emerge. It is not only possible to move sound from one loudspeaker pair to another but also to enlarge it, for example, by playing the stereo track back through several loudspeaker pairs (Teruggi 2005, n.p.).[18]

Michel Chion* calls this live spatialization of the stereo track the external space of the composition. The internal space is the space which is already on the recording itself, for example how the sounds are placed in the stereo panorama or how much and what kind of reverb is used. This internal space is fixed, whereas the external space changes for every performance, depending on, for example, the acoustics of the hall or the amount and kind of loudspeakers (Chion 1998). Performing two-channel works on the Acousmonium is therefore understood as performing an interpretation of the musical work. As a consequence, the same piece can be performed on the same Acousmonium but interpreted in a totally different way by using other loudspeaker combinations and changes in the spatialization of the sound. The interpreter rehearses on the system and needs to know the piece he or she performs very well to be able to conceive a formal plan for the spatialization. The advantage of playing a piece on such a set-up is not only the possibility to interpret it, but to adapt the set-up of the Acousmonium differently to each space as well. For this reason, a composition written for this kind of performance practice can be performed on different Acousmoniums, consisting of a different number and different kinds of loudspeakers. Most set-ups I have discussed in this chapter are used only for a single piece, but the Acousmonium is intended as a universal instrument which can be used for all pieces written in the acousmatic tradition. Compositions for two channels by composers as divergent as Pierre Henry, Luc Ferrari, Christine Groult, Bernard Parmegiani, Annette Vande Gorne, and Åke Parmerud can all be interpreted using this system.

Performances by Eliane Radigue and Der tönende See *by Kirsten Reese: Sound unified in space and dispersed in space*

Regarding the potential of space in relation to microphones and loudspeakers, all the examples I have mentioned until now either use one or several closed spaces (vessels, brass instruments, horn and tubes), or acoustic spaces created through loudspeaker placement and/or loudspeaker type (Luigi Nono and the Acousmonium performance practice). Several examples of the use of the loudspeakers as a point of radiation have been mentioned during this chapter. While the use of *movement* (swinging and throwing loudspeakers) or *material* (loudspeaker sculptures) as parameters for interacting with loudspeakers as points of radiation are quite exceptional, almost all music utilizing loudspeakers must deal with the influence of the performance space on the sound emitted by the loudspeaker system. While for many systems (those discussed earlier, such as 5.1 surround sound or Ambisonics) it is considered best to try to prevent the performance space acoustics from influencing the sound diffused by the loudspeakers too much, many composers use the performance space as a part of their set-up. The next two examples should demonstrate to what kind of extremes sound can incorporate the performance space, and, conversely, how the performance space can incorporate the sound.

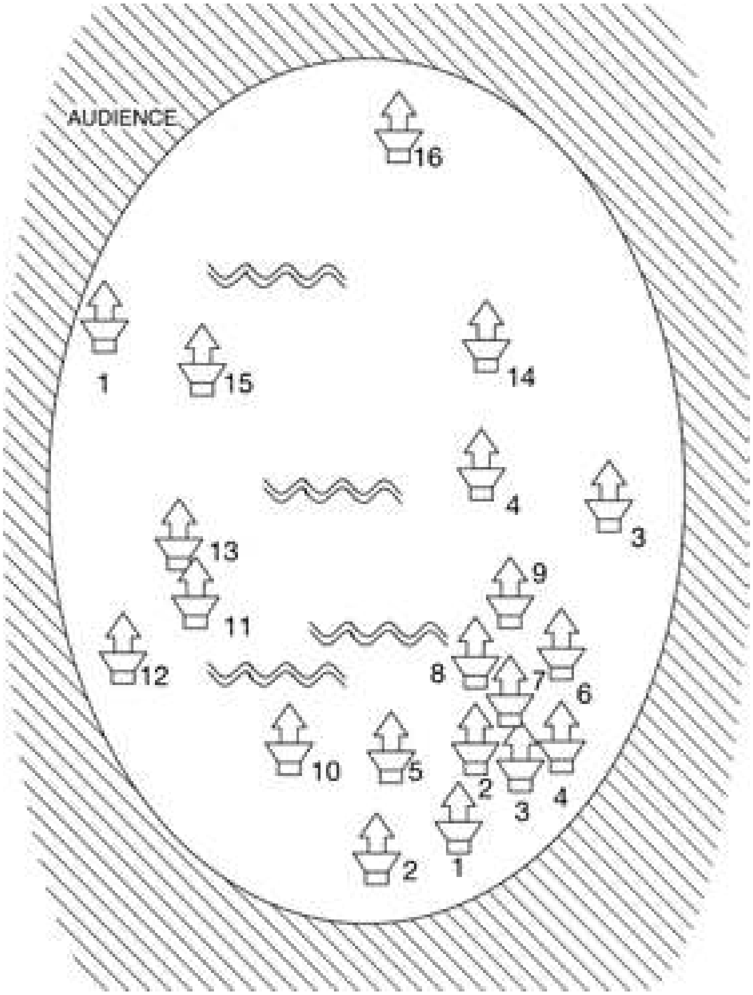
Eliane Radigue* uses four loudspeakers and aims for diffusion of her music in such a way that the room is filled with sound like a 'musical bath' (Scheme 4.22). Unlike the other works I have discussed up to now in connection with the relationship



Scheme 4.22 Eliane Radigue: the four loudspeakers should be placed in such a way that the whole space is filled with sound.

between microphones, loudspeakers and space, this music does not aim to create a clear sonic perspective. The spaces cannot be localized (as in Lucier's *Music for piano with amplified sonorous vessels* or the loudspeakers in the bell of a brass instrument, or the focused loudspeakers project), and neither are several acoustic spaces revealed during the piece (as with Nono's compositions as well as the Acousmonium). In Radigue's work, centrally located areas in the performance space should not sound any better than other places in the room. She uses a stereophonic tape, but sends the tape signal out to four loudspeakers in a cross set-up, similar to the one Anne Wellmer uses in *Green Piece*, so no real stereo image of the sound is reproduced. She points the loudspeakers in different directions according to the acoustic response of the room in order to avoid directionality of sound for the audience (Primosch and Swarowsky 2006, n.p.). There is an interaction with the space, but this time it is not concerned with creating different spaces through which the sounds can travel, but the aim is to create a single sound bath, in which one can no longer differentiate between sound sources. The sound seems to be everywhere, and there is no longer any distinction between space and sound. In everyday life and most concerts as well we hear different sounds from different directions. In everyday life this is often a soundscape of for example a city, with cars going from one side to the other, people talking from a certain direction etcetera. In a concert situation sound is coming most of the time from sources in front of us. It is less common to have several sound sources coming from all directions. What Radigue aims for though is a concert situation during which the same sonic information is coming from all directions. Any hierarchical, distinguishable or recognizable placement of sound sources is avoided. The audience is inside the sound, and the diffusion of sound by loudspeakers could best be compared to the performances by Merzbow, although their differing performance aims result in two different performance practices. The main difference is in the volume of the sound. Due to the high amplitudes of low frequencies in Merzbow's performances, one has the impression that the sound itself has materialized in the performance space and is thus bringing the audience into vibration. In Radigue's performance practice, sound seems to have dematerialized, since the sound is disseminated by the loudspeakers in such a way that there seems to be no starting point in the form of a sound source at all.

In *Der tönende See* (2000) by Kirsten Reese*, loudspeakers travel through the performance space (Scheme 4.23). Unlike the unification of sound and space as achieved in the pieces by Radigue, during which sound is everywhere in space – with the sound sources impossible to locate – in Reese's piece the sound sources are all very well distinguishable from each other and in their different locations in space. She places small loudspeakers and cassette players into twenty-two bowls and sets them adrift from a small boat in a lake (Figure 4.9). The composition has sixteen different audio channels, so the same channel is diffused through two loudspeaker bowls. Due to the water movements of the lake, the bowls slowly move away from each other, each taking its own direction (Reese 2010, 100) (Figure 4.10). The *interaction* with the *space* is achieved through the movement of the different loudspeakers. The path followed by the loudspeakers – playing back a composition with voices telling fairy-tales, sine waves and environmental sounds – might be said to be guided by the performance

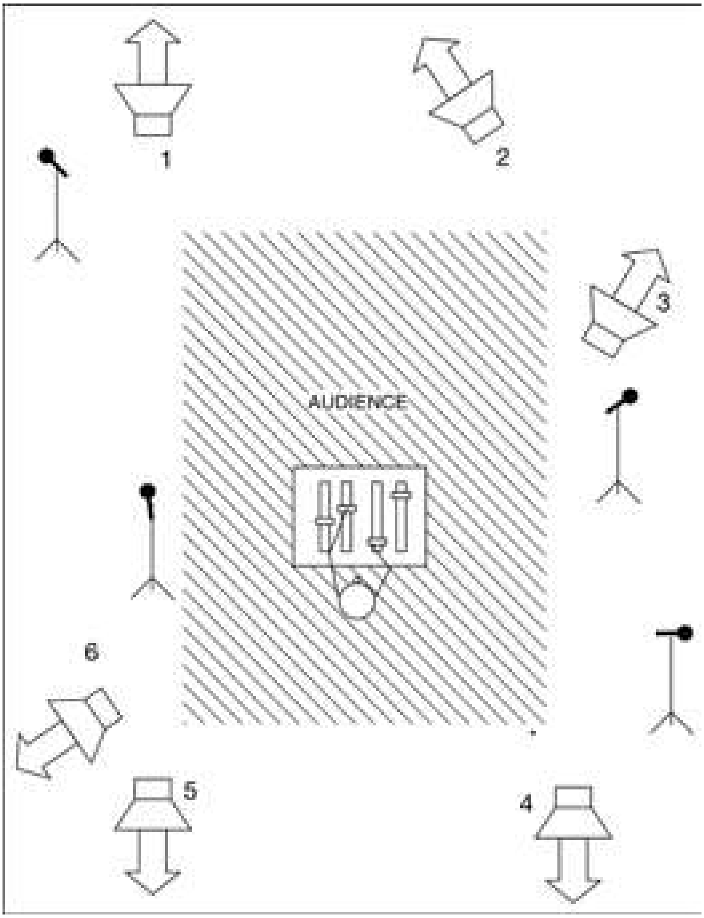


Scheme 4.23 Kirsten Reese *Der tönende See*: twenty-two loudspeakers are placed on a lake. The waves of the lake disperse the loudspeakers in different directions.

space itself. Contrary to the loudspeaker orchestra, whose interpreter decides through which loudspeaker the music should be emitted and at what level, this time the loudspeakers simply radiate their sound while the environment brings them to random places. The audience may follow the loudspeakers by walking along the border of the lake. Since not all loudspeakers move in the same direction, it is impossible to hear all of them at once. The set-up of this piece invites the audience to walk around and to discover the performance space, but this will not constitute entering the set-up itself: if a loudspeaker is in the middle of the lake, its sound will be perceived only faintly, and

Figure 4.9 For *Der tönende See* by Kirsten Reese small loudspeakers and cassette players are placed into bowls. © Kirsten Reese. Photo by Ingrid Schreiber.

Figure 4.10 The bowls with loudspeakers are dispersed in different directions in the water. © Kirsten Reese. Photo by Ingrid Schreiber.



Scheme 4.24 Agostino Di Scipio *Audible EcoSystemics, n.2a (Feedback Study)* sound waves picked up by four microphones are processed by computer software. The result is diffused back in the performance space by six or eight loudspeakers.

there is no possibility of approaching the loudspeaker. Points of sound radiation move through the space, but listeners are not able to enter this space.

Audible EcoSystemics *by Agostino Di Scipio: Closing the acoustic feedback loop again*

In Reese's *Der tönende See*, the lake – and thus the performance space – brings the loudspeakers into movement. In some pieces by Agostino Di Scipio*, the space itself could also be seen as an active contributor to the performance, only this time it influences a live electronic process and could therefore be understood as room-dependent signal processing (Anderson and Di Scipio 2005, 17). In *Audible EcoSystemics n.3a (Background Noise Study)* (2003), Di Scipio places several microphones and loudspeakers in the performance space (Scheme 4.24). The sound in the performance space is picked up by certain microphones and analysed by the computer, and the results of this analysis control the digital signal processing performed by the computer. Since there is no purposeful sound production in the performance hall, what is being picked up is background noise. The resulting signal is sent to loudspeakers, which again project this sound into the performance space. They are placed close to the walls and emit their sound towards the wall instead of towards the audience (Meric and Solomos 2009, 64). The microphones pick up this sound once more, as well as all other background noises sounding in the hall. This piece is shaped by the interaction of microphones, loudspeakers, performance space and digital signal processing. As Di Scipio mentions: 'Just like the microphone, the loudspeaker is not an element foreign to the process; it's part of it, something used to generate the music, not to play it back' (Anderson and Di Scipio 2005, 17). He also points out that all manner of acoustic situations are suitable for the piece, but, depending of the acoustics of the hall, he will place the microphones and loudspeakers differently. The microphone placements during this piece often look strange compared to more conventional microphone set-ups. The microphones are positioned, for example, pointing towards and very close to a wall or in the middle of the room or in a small corner. Depending on these positions, as well as the acoustics of the space, the sounding result will be quite different. The room itself is often processing the sound in ways known from live electronic processing, adding reverb (a sound that is played by a loudspeaker and picked up by a microphone far away will be transformed by the acoustics of the room), filtering the sound (in every room some frequencies will be amplified more than others, which also differs according to placement) and even adding delay (caused by the time it takes for the sound to travel from loudspeaker to microphone back to loudspeaker) (Anderson and Di Scipio 2005, 21–22). The placement of the microphones and loudspeakers in the performance space determines how much reverb is added, what kind of filtering occurs and how long the delay will be. The piece will sound quite different performed in the same space but with a different placement of microphones and loudspeakers.

Di Scipio is interested in unveiling the sound character of the system instead of having sounds transmitted by the system. 'It points the listener to the non-neutrality of loudspeaker technology, turning a problem in high-fidelity engineering into an element of musical experience' (Anderson and Di Scipio 2005, 22). Not only microphones, sound processing by a computer, loudspeakers and performance space act to shape the sound, but the members of the audience also, by reason of their very presence, change the resulting sound. The audience is a part of the set-up, as Di Scipio explains: 'Listeners are a very special kind of external observer or hearer, because their mere physical presence in the room acts as an element of acoustical absorption. Hence they form an internal component of the ecosystemic dynamics' (Di Scipio 2003, 274).

Audible EcoSystemics n.3a (Background Noise Study) can be described as a line of amplification. The starting point of this line points towards the end point of the same line. Although there is no acoustic feedback, the output is continually influencing the input. The background noise of the space is the starting point of the sound, but as soon as the loudspeakers begin to emit sound, this also becomes part of the microphone input. If the microphones or loudspeakers were placed closer to each other, or if the volume was turned up sufficiently, the sound explored at the beginning of this chapter – acoustic feedback – would be the result. This is indeed what Di Scipio does in another piece in the series *Audible EcoSystemics*, namely *n.2a (Feedback Study)*. The main material for this piece is acoustic feedback. Similar to *Nr. 3a*, only microphones and loudspeakers are placed in a hall, again in positions chosen by the composer for their interesting acoustical characteristics. 'Select two locations not too close to the speakers, either inside or outside the area circumscribed by the speakers. Let the two microphones stand possibly higher than the loudspeaker cones. It is recommended that all distances between microphones and speakers are different, in order to determine different audio feedback conditions' (Di Scipio 2014, 4). And about the loudspeaker placement he mentions in the score: '6 or 8 loudspeakers, standing not far from the walls and possibly turned around facing the walls, not the audience. This is to let the total sound consist more in room reflections than direct loudspeaker sound' and 'However, no special assumption is made as to the actual loudspeaker arrangement: experimentation with unusual configurations is recommended' (Di Scipio 2014, 5). The person controlling the electronics intentionally turns the volume up high enough to produce feedback sounds. These feedback sounds are then processed by the computer and sent back into the performance space. A complicated mixture of feedback sounds and processed feedback sounds influences each other, and the whole system of loudspeakers, microphones, space and digital signal processing creates a composition that transforms and develops like an ecological system. But if the loudspeakers would be turned away from the wall again, microphones and loudspeakers were to be placed closer to each other, with the microphones pointing towards the loudspeaker, one would come close to the set-up with which this chapter started: the acoustic feedback set-up for *Quintet* by Hugh Davies.

This chapter ends by considering, once again, a circle of feedback. Whereas in Di Scipio's *Audible EcoSystemics* microphone and loudspeaker placement in the performance *space* are crucial for the resulting sound, in Collins' *Nodalings* – a similar acoustic feedback performance – it is the amount of *material* in between microphones and loudspeakers. In Davies' *Quintet* – again an acoustic feedback piece – the *movements* of microphones are means by which performers interact with microphones and loudspeakers. These parameter changes – in *movement*, *material* or *space* – are each manipulating a closed feedback loop set-up, without a clear start or end point. I began this chapter by investigating possibilities for shaping the sound of microphones and loudspeakers, taking acoustic feedback as a starting point. However, it is not only acoustic feedback, with no recognizable sound source as input, which can cause microphones and/or loudspeakers to become opaque and thus recognizable. Such set-ups can include conventional musical instruments or everyday objects as sound sources, in addition to microphones and loudspeakers. As I outlined in the examples above, besides circles of feedback, what I have termed lines of amplification and points of radiation are systems which are able to support an active shaping of the sounding result.

As I also demonstrated, the set-ups differ in their relation to the audience: the audience may be outside the set-up, inside the set-up or even taking part. These categories are not intended as rigid classifications, but attempts to isolate specific possibilities for *interacting* with microphones and loudspeakers. Almost all my examples exploit an individual set-up, with a specific parameter for *interacting* (movement, material or space), a specific set-up form (circles of feedback, lines of amplification or points of radiation), other sound-producing elements (conventional musical instruments, everyday objects or nothing at all) and the position of the audience (in- or outside the set-up or taking part). In the development of new pieces based on *interaction* between microphones and loudspeakers, one could imagine not only taking these individual strategies as a starting point, but also combining them, for example incorporating the movements in a feedback set-up like used by Davies in *Quintet* with prepared loudspeakers similar to those developed by Tudor in his *Rainforest*. The microphone movements used by Stockhausen in *Mikrophonie I* could be used with a loudspeaker setting similar to that used by Nono in *Guai ai gelidi mostri*. A self-designed instrument like the *Shozyg* by Davies could be diffused on an Acousmonium. I leave here the suggestion of multiple possibilities of *interaction* with microphones and loudspeakers, since all further investigations should be made in practice rather than theory.

As the aforementioned compositions and performances here reveal, microphones and loudspeakers never function exactly like conventional musical instruments. Many composers have claimed that their use of microphones and/or loudspeakers works to transform them into instruments (Nono, Stockhausen, Monahan and Tudor). However, their use of microphones and loudspeakers often results in transformations of the roles of performer, instrument and audience. Microphones and loudspeakers can, for example, become a part of an instrument and, in that way, transform previously unsuitable material into new musical instruments (Oliveros and Davies). In some cases, the audience has to touch a part of the musical instrument to experience the performance (there is physical contact with the loudspeaker in the work of Tudor and Pook, or the sound itself becomes tangible, in the music of Merzbow). Microphones and loudspeakers are able to change a performance practice (listening becomes a creative act in the work of Lucier) or transform everyday actions into music (Maly and Cage). Consequently, the *interaction* discovered in all the music performances discussed in this chapter cannot be called a typical musical instrument interaction, as understood from an analysis of interaction with violins or pianos, for example. This implies that composing with microphones and loudspeakers is substantially different from composing for conventional musical instruments. It is exactly this effort of trying to transform microphones and loudspeakers into musical instruments, and the impossibility of really achieving this, which can produce a much more interesting performance result than that achieved when the goal of making microphones and loudspeakers as normal as all other musical instruments is paramount. In the next chapter, I will discuss why this impossibility is so fruitful and especially how combinations of the four approaches towards microphones and loudspeakers, instead of only the *interaction* approach, can be used as a compositional strategy for making music with microphones and loudspeakers.

Notes

1 The *Resonance* magazine devoted a whole edition to feedback in music and in the arts in general (Aufermann 2002).

2 In Chapter 3, I discussed the invention of acoustic feedback control methods developed by Paul C. Boner.

3 Robert Ashley conceived the piece *The Wolfman* (1964) for amplified voice and tape using acoustic feedback as one of its principal sounds. The feedback is shaped here by the mouth of the performer, who holds his or her mouth as close as possible to the microphone. A tape is played through the loudspeakers at a high volume. By making very soft vocal sounds and raising the volume of the amplification, acoustic feedback occurs. By changing the shape of the cavity of the mouth with different tongue positions, the sound of the feedback is changed.

4 The sound system in the pavilion consisted of thirty seven loudspeakers and two shotgun microphones. These microphones could be routed to the loudspeakers in all kinds of different ways, making it possible to create different movements of sound in space. Tudor decided not to have a sound input to the system but to use only acoustic feedback between the many loudspeakers and microphones. By using the several routings, this feedback would only occur for a short moment between one loudspeaker and one microphone As soon as the input of a microphone moved to the next loudspeaker, the feedback stopped. Tudor describes the process as follows:

> The modifying equipment gave me gating possibilities, since by simply pointing the microphones in space and then having the sound moving between the loudspeakers at certain speeds, the feedback would occur only for an instant. There were marvelous sounds made that reminded me of being on a lonely beach, listening to birds flying around in the air. (Miller 2009, 132)

5 What should be kept in mind is the difference between the energy supply of conventional instruments and that of an acoustic feedback set-up containing microphones and loudspeakers. The energy needed for acoustic feedback is delivered by electricity. Changing the amount of electricity supplied by an amplifier to the loudspeakers might indeed change the sound emitted by the loudspeakers, but cannot be seen as a part of the interaction approach with microphones and loudspeakers, as defined in Chapter 2. The interaction does not take place between the performer, and microphones and loudspeakers, but between the volume slider (or any other control device) which controls the electrical signal and the performer. This way of changing the energy supply is therefore related to the generating approach. What I wish to examine in this chapter is interaction with microphones and loudspeakers, implying that I need to search for a way of changing their energy supply by interacting with them, instead of by manipulating the electrical signal.

6 The fifth player is as well adding some signal processing to the acoustic feedback signal, like ring modulation.

7 These three different aspects of modifying the sound in a feedback set-up as in *Quintet* can be recognized in conventional instrumental playing as well and are relevant in the interaction between musicians and their musical instruments. When considering conventional musical instruments, *movement* is central to the interaction between

performer and instrument. It is often used for supplying energy. This is accomplished by actions like bow movements, string plucking, hitting objects and blowing on reeds and into pipes. This energy generates certain physical vibrations, which act in the audible domain: objects such as strings, reeds and membranes begin to vibrate, exciting other elements, such as soundboards, to vibrate as well. I call this energy supply *movement*, as it brings the object into vibration, and the force, range or quality of movement might change these vibrations.

8 Sum and difference tones are psychoacoustic phenomena of tones produced by the ear, when one is listening to two pitches.

9 Arthur H. Benade gives a comprehensible explanation of what heterodyning is in *Fundamentals of Musical Acoustics* (Benade 1990, 254–266).

10 The Doppler effect is the name for the change in frequency that is perceived when, for example, an ambulance passes by the listener at high speed. The ambulance siren tone is higher when the vehicle approaches then when it is moving further away.

11 The picture is by Jacques-Henri Lartigue and called *My Nanny, Dudu* (1902).

12 There are different types of contact microphones, but I won't discuss them all here. By 'contact microphone', I mean here every type of microphone that is literally making 'contact' with the material it amplifies by touching, through pressure or adhesives, the material.

13 In *Sound Walker*, Ellen Fullman wears the *Metal Skirt Sound Sculpture* in which guitar strings are attached to the toes and heels of her shoes and to the edges of a metal skirt. The strings produce sound as a result of the leg movements in walking, and a contact microphone on the skirt amplifies the sound through a small portable amplifier and loudspeaker system, which Fullman carries over her shoulder like a purse (Fullman 2012, 3).

14 This is my translation and reformulating of:

> So kann ein leises schabendes Geräusch ganz links (Metallzunge wird langsam auf dem Dean Marclay Gitarren Pick-up hin und her gezogen) neben einer höhenlastigen zwischen den Saiten auf und ab wippenden Gabel in der Mitte, (verstärkt durch das AKG unter den Saiten), neben einem rhythmischen Tuckern ganz rechts (Propeller auf Ablage, verstärkt durch AKG unter der Ablage) stehen. (Neumann 2013)

15 There are actually many different names for this type of loudspeaker, often given by the producer of the specific loudspeaker, such as exciters, bass shakers or body shakers.

16 I would like to discuss all *Rainforest* pieces here as being a continuum. As Matt Rogalsky* underlines, the *Rainforest I-IV* pieces (1968–1973) and also the piece *Bandoneon!* (1966) and *Forest Speech* (1976–1979) can be seen as a part of the same project. The title of the piece is coming from the title of a Merce Cunningham choreography *Rainforest I* was commissioned for (Driscoll and Rogalsky 2004, 25–26).

17 Kagel uses a variety of other interaction techniques that transform the loudspeaker and microphone into musical instruments. He asks, for example, fora microphone placed inside the mouth (Kagel 1970, 74–75). He mentions as well in the score that the diaphragm of the loudspeaker should be 'prepared' with all manner of small objects, such as marbles, paper-clips and tissue paper (Kagel 1970, 74–75).

18 Jonathan Prager has written a detailed account on Acousmonium performance practice (Prager 2012).

5

Composing with Microphones and Loudspeakers

Beyond musical instruments: A hybrid of approaches

Although microphones and loudspeakers can acquire characteristics similar to those of musical instruments when there is interaction between performer, and microphone and loudspeaker, they never manage to behave entirely like conventional instruments. Until the invention of sound reproduction technology at the end of the nineteenth century, music had always been produced with instruments. Probably because of this strong relationship between music and instruments, many artists working with microphones and loudspeakers approached these devices as musical instruments, as a natural offshoot of the entire instrument paradigm. '[W]e are now in a period where the media of reproduction and the instruments of musical production are almost by definition cross-bred to the point of unrecognizability' according to Jonathan Sterne, who argues that 'philosophers of sound reproduction have insisted on a rigid distinction between medium of reproduction and musical instrument' although 'musicians and engineers have long since bridged it' (Sterne 2007, n.p.). The hybrid character of microphones and loudspeakers is what distinguish them from conventional musical instruments. For a musician's practice the idea that everything is just a musical instrument leaves out some opportunities for composing with acts of sound creation, which otherwise would be impossible. As I will outline in this chapter, it is highly fruitful for composers and other artists working with sound to approach microphones and loudspeakers not only as musical instruments but to compose for all the different approaches, including those oriented towards transparent sound reproduction: reproducing, supporting, generating and interacting. The wish to compose for microphones and loudspeakers as if they were musical instruments may be considered as an extension of a specific view of music, a relatively conservative one in that it is implied that new means like microphones and loudspeakers should not result in a new kind of music. This view on music implies that music cannot be made without musical instruments, so musicians tend to name all new devices used to create music with – whether gramophone, tape recorder, CD player or the recording studio – musical instruments. The details of musical practice show that quite different compositional techniques are developed when composing for microphones and loudspeakers when using techniques similar to those used for musical instruments. The impossibility of reaching the goal of transforming these devices into 'real' musical instruments led to solutions for microphone and loudspeaker use radically different from the practice of conventional instruments. It is exactly this effort of transforming these new devices into musical instruments that has resulted in highly interesting music, as revealed by the examples in the previous chapter. Besides this, many of the artists discussed in the previous chapter were acutely aware of the impossibility of interacting with microphones and loudspeakers in the same way as with conventional instruments. David Tudor*, for example, mentions that the loudspeaker sculptures should 'decide themselves' how to sound, in contrast to conventional instruments where the performer controls their sound as precisely as possible. The search for various modes of interaction between microphone, loudspeaker and performer has not been unsuccessful by any means. The physical qualities of microphones and loudspeakers may be revealed through *interacting* by means of movement, material or space: microphones and loudspeakers become audible as sound-producing objects by either moving them, attaching objects to their diaphragm or positioning them in space. Microphones and loudspeakers are thus being able to have their own semantic acts of sound creation, not only to reproduce semantic acts of sound creation by others. But it is exactly the combination of these functions – and especially the possibility to alternate between reproducing semantic acts of sound creation by others and producing their own semantic acts – what makes them create their own particular music.

The difficulty that arises when trying to employ microphones and loudspeakers in a way similar to conventional musical instruments is the constant influence of the three other approaches, which use microphones and loudspeakers as transparent devices (*reproducing*, *supporting* and *generating*). Microphones and loudspeakers are primarily designed nowadays to function according to these three approaches. This results in resistance against becoming a conventional musical instrument, since the nature of these devices makes it quite difficult to ignore these other three approaches. This is a very different starting point in comparison to conventional instruments, which serve no other function than that of generating sounds for what is traditionally recognized as music: '[Especially musical instruments, CvE] make possible their own uses; they do not serve an interest that could have pre-existed them' (Evens 2005, 129). Microphones and loudspeakers are multi-functional devices which cannot be limited to one kind of use, which is why I classified them in the second category of objects with which to make music: objects that can produce sound but are not musical instruments in the first place (see Chapter 2). Microphones and loudspeakers have many different functions, depending on the way they are approached.

The four approaches are not only conceptual tools for analysing musical works but also, and especially, tools that can be put to practice compositionally. The categorization of *reproducing*, *supporting*, *generating* and *interacting* are my theoretical classifications, whose mutual borders are not absolute; neither is it easy to find examples that fit exactly within one of these approaches. It should therefore not come as a surprise that nearly all of the pieces I discussed in Chapter 4 make use of elements from other approaches alongside that of the *interacting* approach. The contact microphones used by Valerian Maly*, for example, add a resonating body to objects and, so doing, *interact* with those objects. At the same time, one hears a combination of all elements of the set-up, and the contact microphones could also be considered as *supporting* the objects they amplify. In the piece by Lynn Pook*, an audio signal is played through loudspeakers directly onto the listener's body. These loudspeakers are *interacting* with the body, but the signal they receive is not related to any specific sound source and could therefore be seen as part of the *generating* approach. In all these examples *interacting* is, thus, not the sole approach; elements of one of the other approaches (*reproducing*, *supporting* or *generating*) come into play as well.

In light of this, I believe that microphones and loudspeakers seldom behave exactly as conventional musical instruments. An acoustic feedback set-up might be the closest approach to how conventional musical instruments function, but even in a piece such as *Quintet* the conventional musical instrument set-up is left behind at a certain point. Microphones and loudspeakers can be used in a similar way to musical instruments, but they will always also reveal (one of) the other approaches they are used for. This could be seen as a complication for artists who want microphones and loudspeakers to become 'real' musical instruments. I would claim, however, that these multiple approaches should be seen as a characteristic feature of microphones and loudspeakers. They can be used in a way similar to musical instruments and therefore *interact* directly with performers. At the same time, they can also *reproduce* a sound that is associated with another act of sound creation, and they can *support* another musical instrument or *generate* sounds that are not related to any physical sound source at all. It is exactly this combination that makes microphones and loudspeakers unique in the field of music. To find compositional strategies specific to microphones and loudspeakers, one should therefore not search for their potential to act like musical instruments, but for combinations of different approaches. The analyses of the works in this chapter no longer focus on a single approach, but on their engagement with several approaches. Whereas the *interacting* approach is obligatory to make microphones and loudspeakers 'audible' in a similar way as musical instruments do, the combination with one or several of the other approaches results in a piece that is using the unique features of these devices.

The Edison tone tests: No difference

For the four approaches to be employable as suitable material for composing, their application must be recognizable to the audience. This implies that the audience is able to recognize what kind of role is assigned to the microphone and loudspeaker by the composer. To illustrate how this kind of recognition might function, I will analyse two quite different musical performances in which the *reproducing* approach plays a central role.

In the so-called tone tests, sponsored by Thomas Edison* and executed between 1915 and 1925 (Sterne 2003, 261–266; Thompson 1995) a singer and a phonograph are on stage. Both perform simultaneously, and when the singer stops performing, the phonograph continues alone. Apparently, it was a challenge for the audience to hear who or what is performing (Thompson 1995, 131). An advertisement reporting on the success of an Edison tone test as performed the day before, mentions: 'The end of the concert found the audience absolutely and completely convinced, through its own personal experience, that there is no difference between an artist's living performance and its RE-CREATION by the New Edison, – that listening to the New Edison is, in literal truth, the same as listening to the living artists' (Anonymous 1921, 4) (Figure 5.1). Of course it is more than remarkable that the audience was impressed with the results of the phonograph as

Proved Yesterday!
to
Klamath Falls!

No difference!

Big Audience at the Presbyterian
Church Hears
Helen Clark and Joseph Phillips
in EDISON Tone-Test

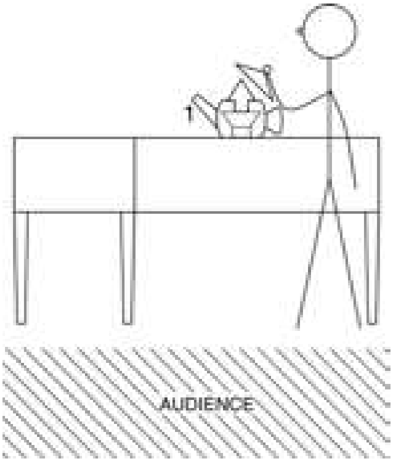
Figure 5.1 An advertisement reporting on the success of an Edison tone test as performed the day before (Anonymous 1921, 4).

compared to a real performer and even more astonishing that the audience claimed not to hear any difference. The listeners attending such a tone test were clearly not listening for the noises of the phonograph, but for hearing a reproduction of the song (Sterne 2003, 280). They knew that the noises and hisses did not belong to the music, and hence did not hear them or, more accurately, just did not perceive or want to perceive them. 'We are not terribly bothered by a poor recording since we are used to constructing from memory the reality of the object "in our heads". To hear is to remember, to recall, not to witness' (Evens 2005, 42). They knew what they were listening for, and as soon as the song and the voice of the singer were recognized, the reproduction was faithful. The audience recognizes that the aim of the machine is *reproducing* a performance, and perceives it as accurate, even when this is, technically speaking, a very bad reproduction. One needs only to listen to an early twentieth-century recording to hear how much the audience must have ignored and added to what they heard.

Reproducing a sound originally produced by another source is never technically perfect. The audible result needs only to evoke a recognizable musical performance for the audience. Of course evoking such a performance is much easier if the singer and the song have just been heard live as well, as is the case with these Edison tone tests.

Nothing Is Real (Strawberry Fields Forever) by Alvin Lucier: A piano in a teapot

The use of the *reproducing* approach as a compositional strategy can be observed in the piece *Nothing Is Real (Strawberry Fields Forever)* (1990) for piano, amplified teapot, tape recorder and miniature sound system by composer Alvin Lucier* (Scheme 5.1).



Scheme 5.1 Alvin Lucier *Nothing Is Real (Strawberry Fields Forever)*: a small loudspeaker is put in a teapot. By moving the teapot lid the sound radiated by the small loudspeaker is modified.

This is the second musical performance I use to exemplify how the reproducing approach might be recognized by the audience. Throughout the first half of this piece, Lucier plays a fragmented and transposed version of the Beatles song *Strawberry Fields Forever* (1967) on a grand piano while making ample use of the sustain pedal. This manner of playing adds long resonances to the short fragments, which are played on different registers of the grand piano. These fragments are recorded during the performance. After having finished the first half of the piece, Lucier stands up and walks towards a teapot. The recording he just made is played during the second half of the performance through a small loudspeaker located inside this teapot. During the playback of this recording, Lucier lifts the lid of the teapot and lowers it again at various moments. These actions are notated very precisely in the score, since they effect a change in the sound of the playback. The surface of the teapot is very hard and smooth, giving rise to many different resonances, which change as soon as the resonance space of the teapot is modified by raising the teapot lid. The spatial aspects of the playback vary in response to these different resonance situations, as does the particular range of the frequency spectrum of the recording itself. The movements of the teapot lid result in sound changes reminiscent of filtering and adding or removing reverb. The teapot seems to 'sing' on the resonance of the piano notes.[1]

In both the Edison tone-tests and *Nothing Is Real*, the audience recognizes immediately that the loudspeaker (or actually the phonograph horn in Edison's case) is *reproducing* a musical performance, although the sound is completely different from the original performance. The loudspeaker in the teapot is very small and will definitely not produce a high fidelity sound and, furthermore, the manipulations of the teapot lid modify the sound extensively. Nevertheless, the audience will recognize the piano fragments, since these have just been heard performed by Lucier on the piano. This is what Raaijmakers defines as one of the positions of the loudspeaker as an illusionist: 'The first is the illusion of recognition, in which case a certain minimum of information is sufficient to bring about recognition and identification with a performer, an instrument or a piece of music' (Raaijmakers 1971, n.p.). In *Nothing Is Real*, the *interaction* approach is used as well, since the loudspeaker functions as an exciter and the teapot as a resonator to form the sound. The combination of the small loudspeaker with the teapot could almost be regarded as a musical instrument. However, the fact that it is a recording of piano music played through the loudspeaker makes clear that there is a difference between this set-up and a conventional musical instrument. Unlike all other sounding objects, loudspeakers often point to a sound source other than themselves. These other recognizable sources are what I termed the semantic acts of sound creation (see Chapter 2) – by recognizing a piano sound when listening to a loudspeaker, one recognizes the semantic acts of sound creation. Concurrently with the playback of the piano recording through the loudspeaker in Lucier's piece, another musical performance is taking place: the manipulation of the teapot lid, which are physical acts of sound creation. The two approaches of *reproducing* and *interacting* take place at the same time. The lifting of a teapot lid, considered in terms of a conventional instrument, might be compared, for example, to moving the slide of a trombone while playing the instrument, resulting in a glissando. The sounding result of the teapot lid movement, however, is much more complex, since the input sound (the piano recording) is constantly changing. The sound produced by the teapot with loudspeaker can be thought of as a reproduction of a piano performance and at the same time can also be heard to produce sound which is intimately connected to the resonating qualities of the teapot itself.

The semantic act of sound creation of the sound emitted by the loudspeaker is a piano performance and not the loudspeaker itself, whereas in a conventional piano performance the semantic source remains a piano.[2] At the same time, the loudspeaker could never be replaced by a miniature piano and performer in the teapot. Even if it were possible, a piano that small could never produce such extended resonances. The total sound would be very different from what the loudspeaker reproduces in the piece. The *reproducing* approach makes it possible to produce a sound with a membrane which would otherwise never have been able to resonate within the teapot. In *Nothing Is Real*, there are two different semantic acts of sound creation perceivable simultaneously: the playback of the resonating chords of the piano, and the irregular resonating glissandi produced with the help of a teapot lid. Microphones and loudspeakers are capable of communicating these semantic sources simultaneously, since they do not have only a single semantic sound source, as other musical instruments do. How is it possible to distinguish between these two semantic acts of sound creation when they occur in one musical set-up, as is the case in *Nothing Is Real*? To answer this question I examine a feature I consider to be crucial for the discrimination between sound sources, the so-called musical gesture.

As long as music could not be reproduced, the identification of semantic acts of sound creation was of no importance. The musicians were always present, and all sound production technologies used could usually be visually verified (Emmerson 2007, 4). In sound reproduction technology by definition the semantic acts of sound creation are not identical to the physical acts of sound creation. For this reason, it was soon recognized that being able to identify the semantic source of the sound waves perceived becomes critical for the success of sound reproduction devices. The actual physical source, the phonograph in the Edison tone tests, is ignored by the audience, and only the semantic source is heard. But in some musical performances, such as *Nothing Is Real*, both physical and semantic source are heard.

Discrimination between different types of sound sources, such as a violin or a piano, has to do with the recognition of the gesture of the sound. What is such a gesture exactly? It could be described in many different ways. Very often, gestures are defined as being related to both the body and the mind, and the most efficient description of what a gesture is seems to be movements of the body with a meaning (Jensenius et al. 2009, 12–13). What makes matters more complicated is that the expression 'musical gestures' is often used not only for movements made by the performer but also for so-called gestures in the music itself. Such gestures, like for example, a motive in a Beethoven symphony, are contained within the tonal, rhythmic or timbral scoring of the work, and do not necessarily need to be realized by the movements of a performer. A musical gesture could therefore be defined more specifically by 'an action pattern that produces music, is encoded in music, or is made in response to music' (Jensenius et al. 2009, 19). Considering microphones and loudspeakers, the first two categories of gestures which produce and are encoded in music are mainly of importance.

In *Nothing Is Real*, there are at least two types of gestures in play: the action pattern of the piano playing and that of the teapot lid movements. For the piano playing to be recognizable, as was the case with the Edison phonograph, no high fidelity recording is needed. Even in the worst conditions, such as through a telephone loudspeaker or through very low-quality headphones, the piano will still be recognized quite easily by an experienced audience (that is, an audience that knows what a piano sounds like). What is listened for in this case is not whether the whole sound spectrum is transmitted by the loudspeaker or how much distortion there is in the frequency response, but the recognition of a specific action pattern. Michel Chion* argues that as soon as an audience is listening to recorded sound without being able to see the source of that sound, listeners will often search even harder for the semantic source of that sound in order to identify it (Chion 1994, 32). The gestures audible in the sound, in this case the gestures of piano playing, help to identify the semantic source. The blurred quality of the recording in *Nothing Is Real* might even intensify the effect of the *reproducing* approach, since the listener has to make some effort to recognize the piano. If this would be a high-quality recording, in a living room ambience or in concert, the piano would be taken for granted. But this small loudspeaker in the teapot forces the listener to search for the piano in the sound and for the piano playing done a few minutes before live in the same room. The *reproducing* aspect is even emphasized as a result of the 'bad' quality recording.

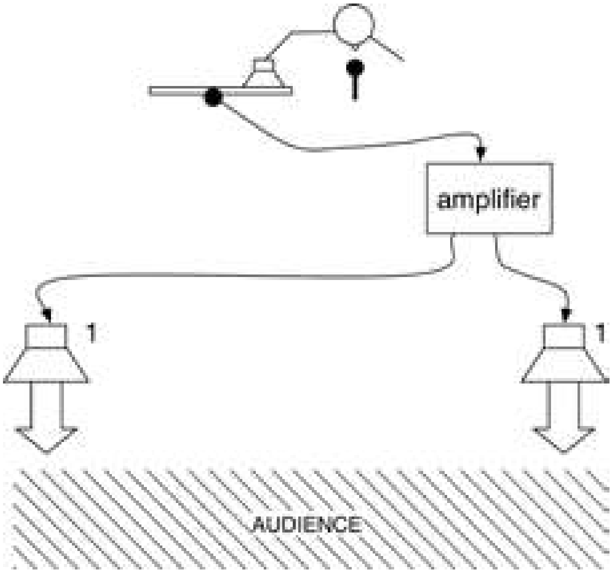
But how are the differences between the piano recording and the effects of the movements of the teapot lid recognized in this performance? The ideas on gestural identity by Paul Craenen* are helpful here. Before the use of electricity, instrumental playing was a process in which the corporal condition of the performer was made audible. Whereas the bodily movements of string and wind performers exert a great influence on the sound of their instruments since constant contact is required to produce it, this influence is much smaller in the case of the piano or of percussion instruments, since only the beginning of the sound can be influenced (Craenen 2014, 150). Sounds requiring a lot of contact with the body of the performer will, for example, sound more 'alive' than sounds that can only be attacked. Craenen calls the specific characteristics of these movement and instrument relationships the 'gestural identity' (Craenen 2014, 170) of the instrument, as a result of which a certain action will result in a certain kind of sound development (Craenen 2014, 168). The gestural identities are formed by a family of musical gestures that are all audibly related to one another.

The one sound-producing object in the second part of *Nothing Is Real*, consisting of a loudspeaker in a teapot, is perceived as containing two different types of musical gestures, referring to two different gestural identities: that of the piano recording and that of the teapot lid movement. The piano recording playback is modified by the teapot lid, and during the performance the listener might oscillate between recognizing the piano recording and the modifications created by the teapot lid movements or perceive both simultaneously. Referring to the several kinds of gestures in music I mentioned earlier, the piano recording consists of sounds containing information concerning gestures encoded in music, and the teapot lid movements produce modifications to this music.

Windy Gong by Ute Wassermann: Singing through the gong

The combination of several gestural identities can lead to interesting starting points for compositions and performances. The several identities do not need to exist next to each other in the same piece, as in *Nothing Is Real*, but one gestural identity can also be transformed into another one. These gestural identity shifts play a major role in the piece *Windy Gong* (1995) by Ute Wassermann* (Scheme 5.2). Wassermann sings through a microphone and holds a small loudspeaker in her hand through which her voice is amplified. A very thin gong is placed next to her and, while holding the small loudspeaker in her hand, she can touch the gong gently with the vibrating loudspeaker(Figure 5.2). A cork is attached to the dust cap of this small loudspeaker to facilitate contact with the gong, since loudspeaker diaphragms are in general concave. The gong is brought into vibration by the vibrations of the loudspeaker. A contact microphone attached to the gong amplifies the gong vibrations through two loudspeakers.

The possibilities of playing the gong with the small loudspeaker differ significantly from normal gong playing, for the most part done with a mallet. The vibrations of the loudspeaker should be seen as very small, fast and soft strokes on the gong. Since these vibrational strokes are as fast as the frequencies that Wassermann is singing, the sound result differs greatly from that of normal gong playing. As long as Wassermann does not touch the gong, the sound coming through the loudspeaker is barely audible for the audience. As soon as the loudspeaker touches the gong, it causes the gong to vibrate. The gong reacts in very differentiated ways to the sounds made by Wassermann, similar to the loudspeaker sculptures in Tudor's *Rainforest*. The gong is *interacting* with the loudspeaker. Whereas small noisy sounds, like whispers, generate considerable resonance in the gong, other more pitch-oriented sounds might trigger much less response, owing to the response tendencies of the gong towards certain frequencies of an inharmonic spectrum When a harmonic spectrum, like a singing voice, is used to 'play' a gong, as is the case in the performance of Wassermann, there will not be much frequencies in this harmonic spectrum that are also present in the inharmonic spectrum[3] of the gong. Noisier sounds will have an inharmonic spectrum containing many different partials and this spectrum will therefore share much more frequencies with the gong spectrum. An exception is the pitch-oriented sounds of the voice that are at the same frequency of one of the resonant frequencies of the gong. They will result in a much stronger response of the gong on these specific harmonic spectra. When the gong resonates as a result of the loudspeaker vibrations, these vibrations are playing the gong. When the gong resonates less, the singing voice becomes the main point of focus. The voice is approached in a *supporting* way by microphone and loudspeaker. There are therefore two gestural identities in this performance: the singing voice amplified through the loudspeaker and the gong played by the singing voice through the vibrations of the loudspeaker.



Scheme 5.2 Ute Wassermann *Windy Gong*: the voice of the performer is picked up by a microphone and amplified through a small loudspeaker. This loudspeaker is used by the performer to bring the gong in vibration. The gong itself is amplified with the help of a contact microphone and two loudspeakers.

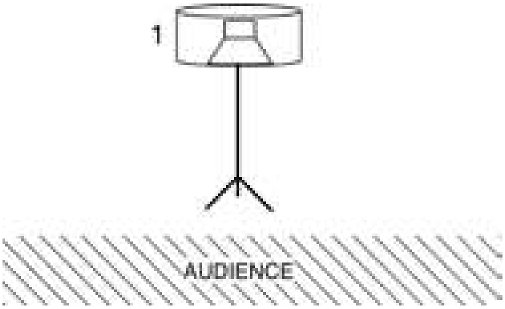
Figure 5.2 A cork with felt on top is attached to the dust cap of this small loudspeaker used by Ute Wassermann to facilitate contact with the gong. © Ute Wassermann. Photo by Ute Wassermann.

The difference between Wassermann's performance of *Windy Gong* and *Nothing Is Real* by Lucier is that transitions can be made from one of these gestural identities to the other. With the sounds of her voice, Wassermann controls response levels of the gong, and she can control whether the small loudspeaker is touching the gong or not. There are two main gestural identities during the performance – the gong played by the loudspeaker and the voice sounds produced by Wassermann – but the majority of sounds emerge from somewhere in between these two identities, and constant transitions are made from one to the other. These are what I would like to call gestural identity shifts: the amplified voice transforms into the resonating gong or vice versa.

The question might arise as to why this voice modification could not be controlled by a simple MIDI pedal or fader, and executed by some live electronic processing of the voice by a computer. This kind of voice processing by electronics is very common nowadays, but causes a rather different result as Wassermann's set-up. First of all, by holding the loudspeaker that reproduces the sound of her voice in her own hand, Wassermann can control the sound modification more directly and react more quickly to the response of the gong than with a fader or pedal that modifies the sound of her voice. She is in actual contact with the gong, whereas with a fader or pedal, there exists an interface in between her and electronic sound processing. As she mentions herself, the reaction of the gong changes with every performance space, and there is always a danger of feedback (Wassermann 2006, n.p.). Flexible control of the loudspeaker-gong contact is essential as well as that all her movements are traceable for the audience. In contrary to a process supported by computer-software, during which, at least for the audience, everything might be assumed possible, there are clear limits to this set-up. Wassermann takes one element from an electronic performance practice, namely the use of loudspeaker amplification, and combines this with elements of acoustical performance practice, her singing voice, and the physical interaction between the gong and the loudspeaker vibrations. In live processing all this would of course occur with the processing of an electrical signal or a digital code. Doubtless the sound of the performance would also be different if the processing were rendered by computer software instead of this physical set-up. *Windy Gong* could also not be performed by means of conventional performance practices, since the gong could never be played by a human in the way that it is played by the loudspeaker. The microphone and loudspeaker are crucial elements in the interactions between the electronic and mechanical aspects of this performance.

Snare drum pieces by Wolfgang Heiniger: Invisible beating

In performances with the *Windy Gong*, the gestural identity shifts are largely controlled by a performer who decides which of the applications of microphones and loudspeakers should be more audible: the physical generation of gong resonances or the amplification of voice sounds. However, these gestural identity shifts can also be composed without taking a performer into account, as is done in the snare drum pieces by Wolfgang Heiniger* (Figure 5.3). The set-up consists of a loudspeaker sculpture that is not played by any performer. Nonetheless, the performance clearly contains gestural identity shifts, but this time, however, only through gestures encoded in music in combination with the visual aspects of the sculpture. Heiniger makes use of snare drums each equipped with a loudspeaker hidden inside (see the scheme of the snare drum (Scheme 5.3)).[4] The first experience in these pieces is the absence of a performer



Scheme 5.3 Wolfgang Heiniger, snare drum: a loudspeaker is placed inside a snare drum, so the sound emitted by the loudspeaker will cause the drum to resonate.

Figure 5.3 The loudspeakers are hidden inside the snare drums, only the cables coming out of the drums are visible in *5 Türme in flacher Landschaft* (2007) for seven self-playing snare drums by Wolfgang Heiniger. © Wolfgang Heiniger. Photo by Wolfgang Heiniger.

for the snare drums. They appear alone on stage, sometimes in combination with other instruments and their players, such as a saxophone or string quartet, occasionally only with other snare drums, but never with a percussionist. For this reason, Heiniger calls them self-playing drums, which sound despite the absence of a player. Sometimes they produce a sound reminiscent of an electronic organ, sometimes a plethora of wild noises and then suddenly the well-known sound of a snare drum itself. These sounds are generated through vibrations emitted by the loudspeaker inside the drum, which causes the snare drum to resonate by means of a process similar to that applied by Tudor and Wassermann. These highly varying sounds are all coloured by the same kind of resonator, the snare drum. Two different relations between the air pressure waves generated by the loudspeaker and the snare drum are used. There are sounds produced by the loudspeaker which cause the snares and the drum membrane to vibrate, and therefore to produce sound. Inaudible movements of the loudspeaker diaphragm are generated as well by the electrical signal. These are in general very low frequencies that are not detectable by the ear but will cause a big air pressure wave to move towards the drum's membrane and snares. The loudspeaker is thus 'hitting' the snare drum, producing movement by low frequency air pressure waves, but without producing any sound itself.

The difference with Tudor's *Rainforest* is that in this case the resonator's sound is already familiar. For this reason the quest for specific resonance characteristics of an object, so important in *Rainforest*, is not so relevant here. In *Windy Gong* both gestural identities – the voice and the gong – are known sources. The sonic outcomes of the snare drum pieces of Heiniger may be placed between those of Tudor and Wassermann: the sound of the snare drum is well-known as are those of the sound objects used in Wassermann's performance, while the sounds coming from the loudspeaker are unpredictable for the listener, since they are generated similar to those emitted in Tudor's *Rainforest*.

Since the audience is familiar with the sound of a snare drum, the visual image of the instrument in itself already summons up strong sonic associations and expectations. In Heiniger's pieces the loudspeaker seems to be in a certain way as passive as those in our living room. It achieves a transformation simply through the fact that it is hidden in a snare drum, which transfigures not only its visual identity but also its audible characteristics. Although the set-up remains exactly the same, the sounds played through the loudspeaker engender gestural identity shifts. If only drum sounds were generated by the loudspeaker inside this snare drum, the set-up would, in terms of sonic output, not differ greatly from a drum-playing musical automaton. In contrast to a musical automaton, however, through the use of the loudspeaker as an exciter for the snare drum, all kinds of sounds become available to the composer. The sounds used to excite the snare drum are not produced on stage; the loudspeaker in the snare drum receives its audio signal from a computer. Due to the fact that the sounds are *generated* by the computer, there is no longer a single gestural identity for the sounds produced by the loudspeaker, as was the case with the piano recording in Lucier's *Nothing Is Real* and the voice amplification in Wassermann's *Windy Gong*. When the result of the air pressure waves emitted by the loudspeaker and resonated through the snare drum sound like a snare drum, the gestural identity will be a snare drum. But as soon as the loudspeaker emits sound through the *generating* approach, all kinds of gestural identities, including morphed, hybrid and indefinable ones, are able to come into being. Although within the *generating* approach any reference to the semantic acts of sound creation is avoided, this does not mean that no musical gestures are encoded in that music. Musical gestures can also be present in acousmatic and electronic music, referring to artificial action patterns created by the composer, consisting, for example, of an increase in energy in the sound, followed by a release. These gestures can be seen as musical gestures made by the composer himself or herself (Windsor 2011, 58–60). Multiple gestural identities can be created in a piece of music, without any reference to an existing semantic source.

In the case of Heiniger's snare drum pieces, the musical gestures have all been encoded into the music, and, owing to the interaction between these musical gestures and the resonances of the snare drum, the sound may be associated with many different gestures. The identity of the snare drum changes depending on the sounds played through the drum: the electronic sounds reveal unexpected sounds latent in the snare drum, whereas the drum sounds fall in line with normal expectations and confirm the gestural identity of the snare drum. The two approaches combined here are the *generating* and the *interacting* approach. As soon as typical drum sounds are heard, and the snares of the drum are excited by these sounds, the listener experiences the drum as being played as if using a drum stick. A clear theatrical aspect enters the performance here, since every stroke of the drum sound reminds one of the absent player. The perception of an instrument being played is accomplished by the sound itself, not through any movement of the player, as was the case in the pieces by Lucier and Wassermann. The characteristics of this sound in combination with the visual associations of the snare drum give rise to an association with an instrumental practice.

These self-playing drums reveal another area of potential in composing for loudspeakers: the musical gesture encoded in the sound itself in combination with a clearly identifiable resonator can engender many gestural identities. Usually a sound serves to identify the object that has produced the sound. It is easy to recognize if an instrument has been bowed, blown or struck and whether the material is wood or metal. The sound itself often also reveals if, for example, the degree of force with which a string is bowed and where it is bowed. But in Heiniger's snare drum pieces, the sounds which seem to be produced by the object can also produce characteristics that do not belong to it. The bizarre and unexpected sounds of the drum put into question the musical instrument's identity, which at first seemed to be so fixed.

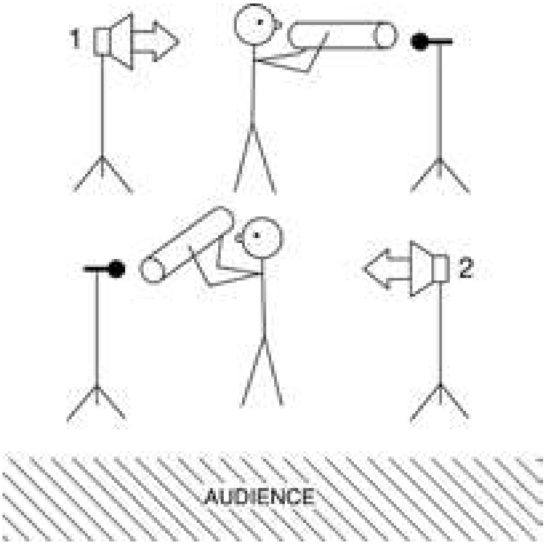
In Heiniger's pieces, the relationship between the sound-producing objects and the sound itself is constantly changing, and the compositional plan can be regarded as a development of these shifts from one relationship to another. Sounds are combined with an object – the snare drum – with which they would otherwise never be connected. The snare drum is enabled to produce sounds that it would never produce without the intervention of the vibrations produced by a loudspeaker. At the same time, the sounds emitted by the loudspeaker would sound significantly different without the resonance of the snare drum. These relationships can be developed further. This results in musical works in which relationships between performer, instrument, sound and audience can be composed.

Analysing instrumental playing without the use of any electricity, one could say that intentional movements by a performer are transformed into vibrations of an object, which are perceptible as sound to human beings. These direct relationships between movements, body, vibrations and materiality were valid for the production of music until the invention of technologies for sound recording and sound reproduction, and could be dismantled as soon as it was possible to transmit sound through space or time. Physical and semantic acts of sound creation are not identical anymore. The loss of the direct relationship between the moving body of the performer and the vibrating material of the instrument, or, in other words, between what is heard and what is seen may be thought of an opportunity to compose these relationships anew. By working with sound waves which are transduced into electricity, and electricity transduced into sound waves, these relationships become totally arbitrary and open to any kind of connection between gestures and resultant sound (Miranda and Wanderley 2006, 2–4). A very soft sound in front of a microphone could cause a very loud sound to be emitted by the loudspeaker, or vice versa. The reaction of an electric instrument no longer depends on the laws of classical mechanics, but is dependent on the way the several parameters of the resulting sound are connected to the incoming signal. When microphones and loudspeakers are the main focus of compositional strategies, the potential of both these worlds, mechanical and electrical, become available to the composer. This implies, as the examples above demonstrate, that inherent relationships between performer and instruments can be combined with composed relationships.

tubes by Paul Craenen: Musicians, dancers and technicians

Paul Craenen argues that as soon as a musician produces sound with a new or unique set-up, then this set-up itself becomes a focal point. ‘What attracts the attention during a musical performance with an instrumental innovation is also the ins and outs of how the sound is produced and the way that phenomenon is treated’ (Craenen 2014, 194). Craenen calls this a new compositional parameter, since the situational aspect of sound production becomes part of the compositional process. The instrument becomes an essential part of the composition itself, instead of being a well-known device which merely translates the performer’s expression. These new set-ups might call for unknown or unexpected gestures in sound production. An example is the teapot lid movement in Lucier’s *Nothing Is Real*: as far as I know, no other composition exists in which the position of a teapot lid is an important parameter.

In the performance *tubes* (2007) by Craenen himself, two microphones and two loudspeakers are used, facing each other in a rectangle on stage (Scheme 5.4). The principal sound is acoustic feedback. All changes in sound in the piece are triggered by the performers, who place grey PVC tubes normally used as drainpipes in front of a loudspeaker or a microphone. These tubes resonate the sound waves produced by the



Scheme 5.4 Paul Craenen *tubes*: acoustic feedback between two microphones and loudspeakers is manipulated by two performers with the help of PVC pipes. The microphone input is processed by a computer software, depending on the amplitude of the microphone signal.

loudspeaker and – analogously to the relationship between the length of a flute and its pitch – force the feedback towards a frequency which is inversely proportional to the length of the tube, in the course of which the overall amplitude will also increase owing to the increased resonance of the sound. During *tubes* the kinds of movements Craenen uses are not only novel to musical performance but the manner of these movements also changes during the performance. According to Craenen:

> During the creation process of *tubes*, special attention was paid to the status of the performing bodies […]. The performer's identity oscillates between the identity of a dancer executing choreographic movements in a disciplined way, the identity of a musician playing the tubes in a close interaction with what he/she hears, and the identity of a technician testing out sound possibilities and constructing a feedback instrument (Craenen 2008, n.p.).

As soon as the performance starts, it becomes clear that there is more going on than just manipulation of the sound through altering the acoustic conditions of the set-up by means of the tubes. Many more aspects of the sound change as soon as tubes are placed in front of a loudspeaker or a microphone than just their resonance frequencies and amplitudes. In between the microphone input and the loudspeaker output is computer software, which processes the incoming sound according to the amplitude of the microphone signal. Each time the volume of the sound increases, a border is crossed in the software, and a new preset is activated. As soon as the volume decreases again, the preset switches back to the preset belonging to this lower volume level. There are five levels of software preset changes, the fifth level being reached when a tube is placed in such a way that microphone and loudspeaker are directly connected to each other, therefore producing the loudest possible feedback levels for this set-up. Each level is processed live in a different way, applying techniques such as pitch shifting and granular synthesis to produce short melodies, clear pitches, fuzzy noises or rapid glissandi, depending on which level is active.

The audible result is in part related to the acoustic laws of the physical world: larger objects, in this case larger PVC tubes, result, for example, in a louder and lower sound. The combination of tubes, their distance from the microphone, and the possibility of changing the acoustic characteristics of the tubes by closing one end with a hand result in endless possibilities for playing this feedback system, and all these changes are immediately perceptible in the resultant sound. The performers' gestures are *producing* music, and the performers are *interacting* with microphones and loudspeakers. At the same time, the electronic processing creates an additional alteration of these sounds, for example small melodies, not played by the performers but generated by the computer software with the acoustic feedback audio input, which contain their own kind of gestures, encoded in the music. This aspect of the sound production is no longer related to acoustic laws but only to digital sound processing, and is therefore clearly an example of the *generating* approach: the acoustic feedback sound is used as input for a variety of sound processing which is not related to the gestures of the performers, but which instead generates its own gestural identity.

In this work the performers themselves change their identity as well – dancer, musician, technician are the words Craenen uses to describe their roles (Figure 5.4). There are choreographic parts during which, with the help of short tubes, high-pitched feedback sounds are produced by the 'dancers'. At other moments in the performance, an installation is built by 'technicians', with many connections between the microphones and loudspeakers. The computer software now *generates* a low and fast-moving sound structure. The 'musicians' identity of the performers, the third identity, is created through the direct *interaction* between the performers, the tubes and the microphones and loudspeakers. The performers 'play' the set-up as if it were a musical instrument.

The different identities the performers can have in *tubes* is an interesting aspect in relation to the possibilities of playing an electronic instrument. With electronic music, it is not easy to achieve the degree of control commonly experienced with conventional instruments, since the relation between movement and sound is no longer the inevitable result of the mechanics of the instrument. As is often argued, the control of electronic sounds needs to take place 'intuitively' (see, for example, Knapp and Cook 2005), which can be complicated since any physical action of the performer can result in a completely unpredictable sound output. In a non-electronic environment, the relationship between body and sound could be called 'predictable', but as soon as electricity is used in music this predictability is lost. Electronic sounds, whose only point of connectivity to the resulting sound often seems to be a 'turn on turn off'

Figure 5.4 Paul Craenen and Cathy van Eck perform *tubes* by Paul Craenen, here in the 'technicians' identity. © Paul Craenen. Photo by ChampdAction.

button, do sound unmediated in comparison with conventional musical instruments (Wishart 1996, 180).

Whereas many efforts have been made to obtain this kind of direct control in electronic music (Knapp and Cook 2005), I find that it is exactly the separation between the category of gestures used to produce music and the category of gestures encoded in music which can be fruitful for experimentation and creativity. In *tubes*, for example, the 'technician identity' is realized through a gesture by the performers that might be described as essentially 'putting an object in the right place', which is in fact an act similar to an on/off button of a controller for electronic music. The audible result is unrelated to the corporeal actions of the performer. Whereas this might be experienced as a negative aspect according to conventional musical instrument design, I feel that it is very valuable for this particular performance. If the set-up were a transparent musical interface, gestural identity shifts such as those happening in Craenen's piece would not be possible. Unique relationships between a performer's gesture and the resulting sound may be constructed, and changes in these relationships composed into the formal structure of the musical work.

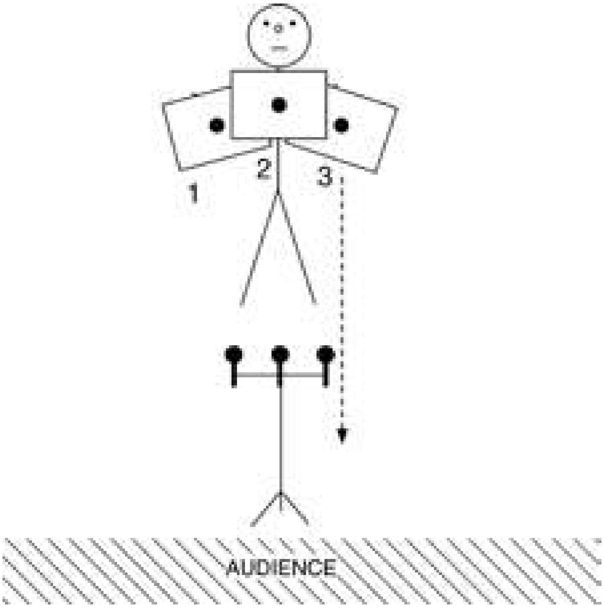
The development of most musical instruments has been one of trial and error, often until a form was found which was considered to be 'finished' by the musicians playing these instruments and/or by the instrument-makers. Most traditional instruments, such as pianos and violins, have found a form that seems to be accepted by musicians as their – at least during the last century – final form. Many of the examples discussed in this and the previous chapter, however, incorporate instruments which could not be described as finished, remaining rather in an experimental state, in which they only partly function, their reaction is very precarious, or they are easily modified into something else. Instead of being highly sophisticated objects which can be controlled by experienced musicians with a high level of precision, these set-ups seem to be the opposite: they are not highly controllable, and the musician plays a different role from that of mastering the instrument. Such absent and unfinished aspects of the pieces keep the relationship between performer, object and sound in constant motion and create the possibility of composing with these relationships.

These unfinished instruments could be called 'open musical instruments'. Dick Raaijmakers describes conventional musical instruments as being 'closed'. Although they can be opened, for cleaning them, repair or tuning, they only become playable when they are closed again (Raaijmakers 1989, 9). Raaijmakers mentions that at the end of the nineteenth century most instruments were used in closed form, and could be called a purely technical product which was 'finished'. During the second half of the twentieth century, a development took place in which many instruments were 'opened',[5] as Raaijmakers calls this process, by musicians, artists and composers, evolving into forms varying from 'work of art' to 'work in progress' (Raaijmakers 1989, 12). Raaijmakers curated an exhibition for the musical instrument department of the municipal museum of The Hague which included numerous open musical instruments. All works in this exhibition consist of conventional instruments, such as pianos and violins, which have, in some way, been opened by artists. One of the exhibits was the tam-tam set-up for *Mikrophonie I* by Karlheinz Stockhausen, as described in Chapter 4.

Not only Stockhausen's tam-tam but also Ute Wassermann's gong and Wolfgang Heiniger's snare drum could be described as open instruments. While pieces with PVC tubes (Paul Craenen), weird sculptures (David Tudor), a tea pot (Alvin Lucier) or simply microphones and loudspeakers (Hugh Davies) are not related to any conventional musical instrument at all, I still consider these set-ups as open musical instruments. It remains unclear what the final instrumental result will be. Craenen uses this unfinished feature of these kind of set-ups to create several identities: PVC tubes are not associated with music in the first place, but can become (a part of) a musical instrument as a result of the actions of musicians who treat them as such in the course of the piece. In Craenen's performance, the form of the open musical instrument is in constant fluctuation, being built, taken apart, or rebuilt in another form by the performers.

Open Air Bach by Lara Stanic: Speeding up a sonata

The last performance I will examine is *Open Air Bach* (2005) by Lara Stanic* (Scheme 5.5). Although visually quite different, the performance set-up for Stanic's performance is technically similar to that of Hugh Davies for his *Quintet*, and uses the distance between microphone and loudspeaker to control the parameters of the performance. Unlike Davies, Stanic does not work with acoustic feedback sounds, but



Scheme 5.5 Lara Stanic *Open Air Bach*: The performer has three small loudspeakers attached to her body. Through each of the three small loudspeakers a sound file is played. Depending on the amplitude of the input signal of three microphones, the sound files are played faster or slower. The closer the performer gets to the microphones, the faster the sound file is played.

uses the amplitude of the sound waves picked up by the microphone to control several parameters of the output of the loudspeaker, also called data feedback. The amplitude of the microphone input, and not the sound waves oscillating between microphone and loudspeaker, controls the sound processing in the computer. The resulting sound is emitted by the loudspeakers and once again picked up by the microphone.

For this performance, three very small loudspeakers without a diaphragm are each attached to a sheet of paper which itself functions as a diaphragm. Their material is piezo ceramic and the can also be used as contact microphones. These paper-loudspeakers are attached to the performer's body (one on each arm and one on her chest) as she walks towards a stand on which three microphones are attached. A soft sound is heard from the loudspeakers. During her walk towards the stands the sound becomes louder and louder, the playback speeds up, and instruments, melodies and harmonies become recognizable. A piece by Johann Sebastian Bach is heard, in a very unstable version, with pitch and speed of the piece in constant fluctuation.

In Stanic's performance, the sound produced is not acoustic feedback, but the three instrumental parts for flute, violoncello and cembalo of the E-minor Sonata of Johann Sebastian Bach are each emitted through one of the three small loudspeakers. The playback speed of the sonata depends on the volume level of the microphone input. At the beginning there is the largest distance between Stanic and the microphones, so the playback speed is very slow, resulting in a very low and slow performance of the sonata. As soon as she approaches the microphones, the level of their input becomes louder and the sound emitted by the loudspeaker therefore becomes higher and faster as well. As Stanic herself phrases it, the task of the performer is to bring these three instrumental parts towards the right pitch and playback speed, so that the Bach sonata is reproduced as accurately as possible.[6] This is no simple task, since fluctuations in volume of the Bach piece will change the speed again as soon as an optimum position is found. During the performance, she continually searches for a new position at which the piece can sound at the correct speed. Whereas a certain movement might bring one of the three loudspeakers closer to the microphone, it will simultaneously change the distances between the other two microphones and loudspeakers. Stanic is not playing the Bach piece, but the Bach piece is playing her, so to speak, and forces her to make certain movements to accomplish her task. The movements during the performance reveal a constant searching for control of the sound by the performer, a control that will never be achieved (Figure 5.5).

With this work, the *reproducing* approach is put to use as a kind of score for the performer's movements, resulting in gestures of the performer that look stiff, unnatural and as if the performer is being coerced into making them. They are clearly not the articulated gestures of a musician who is 'in control'. Stanic's gestures contrast greatly with the musical gestures suggested by the playback of the Bach sonata: the gestures encoded in music which will be, at least partially, heard by the audience of *Open Air Bach*, as well as the gestures that *produce* music which can only be imagined by the audience, are fluent and expressed in a comprehensible way. An audience

Figure 5.5 Lara Stanic performs *Open Air Bach*. Video still. © Lara Stanic.

familiar with the music of Bach can mentally reconstruct these gestures, even despite the extensive deformations caused by the speed changes. Additionally, Stanic is a flute player herself, who thus knows the music-producing gestures of this piece very well. Her movements contrast greatly with the original movements of the flute player. The two approaches here, *reproducing* and *interacting*, do arise from the warped playback of the Bach piece. Due to the recognizability of the semantic acts of sound creation the audience is continuously listening for the *reproduced* Bach performance. The gestures of the performer, trying to achieve this correct rendition of the Bach sonata, involve unusual, awkward gestures that seem to have no relation to it, or indeed to music in general. The *reproducing* approach – the Bach piece as it should 'normally' sound – controls the *interaction* between performer, and microphones and loudspeakers. The performer is physically searching in this piece to bring the microphone and loudspeaker back to their identity as transparent devices for sound reproduction.

Resistances and resonances of microphones and loudspeakers

With the use of electricity, resistances and resonances of a set-up can change during the performance. Impossible to achieve with conventional instruments, by using electricity to connect gesture to sound exactly the same movement can result in a different sound. At the same time, the physical component of microphones and loudspeakers also brings in some specific resonances and resistances that cannot be composed due to their dependence on laws of classical mechanics. No longer interested in a perfectly functioning instrument, many artists create unstable set-ups that are in constant motion. The resistance and resonance therefore often fluctuate in their performances. Compositions become a discovery of the possibilities of (dis-) connections between the sight and sound of the set-up itself and, therefore, of the many potential identities of the set-up.

In many of the more recent works I discussed, especially the works by Wassermann, Heiniger, Craenen and Stanic in Chapter 5, the artists *interact* with microphone and loudspeaker, but not with the aim of using them in a way similar to a conventional musical instrument. They seem to be interested in these devices especially due to the characteristics that *distinguish* them from conventional instruments. Taking Stanic's performance as an example, it is clear that if she were able to reproduce the Bach performance easily and perfectly, her performance would not make much sense anymore. The task of accomplishing an accurate playback of the Bach recording is impossible, since the set-up does not permit this. The performance is not about the virtuosity of the musician or the perfect interpretation of a score. Stanic is disposed to a constant struggle to achieve the impossible; and owing to the recognizability of the Bach piece, the audience knows exactly what she is struggling for. This is completely different from what is the case in many compositions for conventional instruments, when the performer rehearses the piece well and the audience will have the impression that the performer thus masters the composition on her instrument, when she performs in public. The works created by artists working with microphones and loudspeakers lead to the necessity of composing the relationships between performer, movements and sounding results. Various relationships between what is audible and what is visible develop during the pieces.

Since we do not connect a very specific sound with microphones or loudspeakers, as would be the case with conventional instruments, their identity depends on the context. This context is formed by playing them and therefore creating or strengthening an identity. By using the unique characteristics of microphones and loudspeakers as sound producers, other aspects of composition can come into focus that differ from composing for conventional instruments: a composition can focus on identity shifts of the sounding objects themselves, since the instrument does not have an identity as rigid as the piano or violin. As the many examples in this book have proven, the different possibilities of microphone and loudspeaker set-ups are flexible in sound as well as in playing method.

Answering the question I started this book with, I conclude that microphones and loudspeakers hold a unique position in the realm of sound producers, a proposition that I have supported through developing four approaches towards them. It is especially the combination of their ability to function as physical sound producers (the *tuning fork principle*) and their ability to act as seemingly transparent sound transmitters (the *tympanic principle*) that makes them exceptional in the field of objects with which music can be made.

The future of microphones and loudspeakers: Between air and electricity

The development of conventional musical instruments generally involves an intensive collaboration between musician and instrument maker. Microphones and loudspeakers are not expressly designed for the kind of application as in the musical works I described in the last two chapters, but principally for transmitting sound without becoming audible themselves. Thus, the search for the transparent microphone and loudspeaker continues. In microphone technology, for example, one might note the development of optic microphones, laser microphones and microphone array systems, using a large number of individual microphones for creating highly directional output. Although the microphone is already a highly sophisticated device, developments in the area of increased directionality as well as an increased use of digital signal processing might be expected (Rayburn 2012, 8).

Until recently, the Kellogs-Rice loudspeaker from 1924 (see Chapter 2) has been the foundation for the majority of loudspeaker design techniques. However, several new technologies have been introduced in recent years, for instance, to develop loudspeakers which project their sound in a specific and focused direction, so that the person for whom the sound is intended can hear it and no one else is disturbed, or to develop ways of concealing the loudspeaker in a flat panel (Klaß 2009). These devices no longer incorporate a moving coil and stable magnet, but implement different technologies, such as using two attached membranes (Flat

Flexible Loudspeaker, FFL [Klaß 2009]), the possibility of printing loudspeakers on paper with the use of flexo printing technology (Kolokathas 2012) or applying the thermoacoustic effect of carbon nanotube technology (Xiao et al. 2008, 4539). The result is that many of the techniques discussed in this and the previous chapter no longer apply to these new loudspeakers. For example, loudspeakers might utilize the thermoacoustic effect: if a temperature oscillation (a rapid change in the temperature of a particular material) is effected, a pressure wave will be excited as well (Xiao et al. 2008, 4542). This (air) pressure wave is perceived as sound to human beings as soon as the frequency lies within our hearing range. Loudspeakers constructed with carbon nanotube technology are flat, flexible and stretchable and can be tailored into many different shapes, or attached to all kinds of flexible materials, such as clothes or flags. Even if the thin film is partly broken, it still produces sound without distortion, which is impossible for the diaphragm of the conventional moving coil loudspeakers. The thin film of carbon nanotubes does not vibrate like a conventional loudspeaker diaphragm, so that attaching an object to it does not bring that object into vibration, the phenomenon used in the pieces by Tudor, Pook and Wassermann. Thirdly, the strong directional aspects of the FFL technology no longer allow for an interaction between sound and space, as used by Nono. If these technologies for flat loudspeakers become established – and they probably will, since the transparent loudspeaker still forms an ideal for the sound reproduction industry – new opportunities for composing with microphones and loudspeakers will certainly come into existence as well.

Although the technology will change, the main characteristics of microphones and loudspeakers will most likely remain the same. The devices transduce sound waves into electricity (or perhaps another form of energy) and back, but are intended to remain transparent. As the examples above show, current developments are focused on making microphones and loudspeakers smaller and flatter. Composers and musicians will be mainly dependent on what the sound reproduction industry develops in the future to facilitate transparent sound reproduction, a paradigm quite different from that applied in the development of objects to be used only as musical instruments. Whereas for conventional musical instruments, the wishes of musicians and composers for the instrument as music *producer* are central, microphones and loudspeakers remain in what I called the second category of objects with which to make music (see Chapter 2): devices which deal with sound but which are not intended to produce music in the same way as a conventional musical instrument. The new developments described above thus take place in the absence of any substantial influence by artists who use microphones and loudspeakers for developing musical performances. What artists might wish for is probably to realize further possibilities of interaction with microphones and loudspeakers through movement, material or space, the three categories I mentioned in Chapter 4. For movement, it would be desirable to have microphones and loudspeakers which are very light, wireless and/or rotatable in all directions. Whereas these features are partially available in the current microphones and loudspeakers, improvements could certainly be made.

Wireless loudspeakers are not yet very common, and the wireless microphone does not have a large movement radius due to the relatively large transmitters which it often requires. Regarding material, flexible microphones and loudspeakers which could be attached to all kinds of materials, such as clothes, and/or cut into all manner of forms, would certainly be desirable to many artists. For interacting with space, more control of the directionality of microphones and loudspeakers could be achieved, especially the latter, making it possible for example to focus the sound in a line through space. What all of these developments have in common is once more a different way of dealing with sound from that found in any conventional musical instrument. Many of these options seem to be close to the developments in the industry.

The technical construction of microphones and loudspeakers will certainly change in the near future. It might be that the moving-coil loudspeaker, as described in the Kellogs-Rice patent, will become obsolete. Many of the musical works I described in the last two chapters will then become impossible to perform. However, the necessity of implementing some transformation between air pressure waves and electricity (or some other form of energy) remains. Although their main function will probably be to transmit sound without being audible as sound shapers themselves, and though they may become more and more transparent, microphones and loudspeakers will retain their physical presence, and we can look forward to discover astonishing and exciting ways to compose for these new kinds of microphones and loudspeakers.

Notes

1 A similar approach of filtering the sound of a loudspeaker by changing the space it is surrounded by can be found in *Small Voice* by Laurie Anderson* and *Silence Is My Voice* (2005) by Matthias Kaul*. The performer has a small loudspeaker in her mouth. By opening and closing her mouth, the resonance space for the loudspeaker changes and directly affects the sound.

2 Of course, many instrumental pieces mimic sounds, such as the *Sonata Representativa* (1669) by Heinrich von Biber for violin. In mimetic compositions the musical instrument, in this case the violin, will never disappear. The piece will always be primarily a piece for violin. This is never the case as soon as microphones and loudspeakers reproduce a sound.

3 A harmonic spectrum is a spectrum which partials are all whole number multiples of the fundamental frequency. As soon as there is any deviation of this a spectrum is called inharmonic. The sounds of instruments like gongs and bells are inharmonic spectra.

4 Pieces written for snare drums containing loudspeakers by Wolfgang Heiniger:

- *Lamento III* (2003) for contrabass saxophone, percussion, two self-playing snare drums and electric motor.

- *Lamento V* (2003/04) for string quartet and self-playing snare drum.
- *Engelszungen* (*Lamento IX*) (2004) for ensemble and two self-playing snare drums.
- *Desafinado* (2005) for soprano saxophone, self-playing snare drum and loudspeakers.
- *5 Türme in flacher Landschaft* (2007) for seven self-playing snare drums.
- *Schwingkreis* (2010) for snare drum and two self-playing snare drums.
- *Flatscape* (2010) for ten self-playing snare drums.

5 I decided to employ the term 'opened', since this is how Raaijmakers calls the act of altering, transforming or even destroying conventional musical instruments (Raaijmakers 1989, 11).

6 As soon as Stanic reaches the right playback speed, several pieces of papers attached to the microphone stand start rotate. Since this aspect of the performance is not important for my analysis of Stanic's use of microphones and loudspeakers, I will not address this.

Appendix Biographies

Ablinger, Peter (born 1959) is a composer writing for musical instruments and who creates electronic music and sound installations. In many of his works he focuses on varied aspects of so-called white noise.

Anderson, Laurie (born 1947) is a composer, performance artist and violinist. She is known for her experimental use of sound technology on stage, using different types of modified violins (for example, the tape bow violin) as well as for processing the sound of her voice.

Ashley, Robert (1930–2014) was a composer. Mainly focusing on opera and multidisciplinary works, he is well-known for his television operas.

Bayle, François (born 1932) is a composer, principally of *musique acousmatique*. He was the head of the Groupe de Recherches Musicales (GRM) from 1966 until 1997.

Behrman, David (born 1937) is a composer whose compositions and installations concentrate mainly on interactive real-time relationships with (imaginative) performers, sometimes involving the audience.

Bell, Alexander Graham (1847–1922) was a scientist who undertook extensive research and patented several inventions in the area of telecommunications.

Bernier, Nicolas (born 1977) is a composer and sound artist, composing electronic music and creating audiovisual performances and installations. His recent works often uses tuning forks, based on Helmholtz's experiments.

Boehmer, Konrad (1941–2014) was a composer and writer on music. He was the director of the Institute of Sonology in The Hague from 1994 until 2006.

Boner, Charles Paul (1900–1979) was a scientist working as a member of the Physics department of the University of Texas (1920–1970). He was specialized in acoustics and undertook research on acoustic feedback and sound systems.

Cage, John (1912–1992) was a composer. He is known for his very experimental approach towards music in general, using chance as a compositional method, focusing on everything that is audible and often collaborating in other disciplines, such as dance.

Chion, Michel (born 1947) is a composer of *musique concrète* and a writer. His texts focus on the relation between the auditory and the visual, especially in the cinema.

Collins, Nicolas (born 1954) is a composer of electronic music. His installations and performances deal with uncommon uses of electronic equipment as well as with 'misuse' of musical instruments.

Comers, John J. (year of birth and death unknown; active at the beginning of the twentieth century) was a scientist who principally focused on microphone technologies.

Craenen, Paul (born 1972) is a composer and researcher, integrating choreographic and corporeal aspects in his compositions. He is the director of Musica, Impulse Centre for Music.

Davies, Hugh (1943–2005) was a composer, musicologist, and inventor of experimental musical instruments. He has invented numerous new instruments and written many articles on electronic instruments.

De Forest, Lee (1873–1961) was an inventor, most well-known for his invention of the Audion, the first triode vacuum tube. This electronic component was essential for the development of amplifiers of the electrical signal used in sound reproduction technology.

Dieckmann, George F. (year of birth and death unknown; active at the end of the nineteenth century) was a German scientist who emigrated to the United States, where he was among the first researchers on possible applications of electricity.

Di Scipio, Agostino (born 1962) is a composer, sound artist and musicologist. His works focus principally on unconventional sound synthesis and processing methods.

Driscoll, John (currently active) is a composer and one of the founding members of the group *Composers Inside Electronics*. He uses instrumental applications of microphones and loudspeakers in many of his works.

Edison, Thomas (1847–1931) was an inventor who worked on the light bulb, the phonograph and the motion picture camera.

Eisenmann, Richard (year of birth and death unknown; active at the end of the nineteenth century) was a Berlin-based lawyer working at the physical institute of the Humboldt University in Berlin and a student of Hermann von Helmholtz.

Ellis, Alexander (1814–1890) was a mathematician and a philologist. He translated *On the Sensations of Tone as a Physiological Basis for the Theory of Music* by Hermann von Helmholtz.

Fullman, Ellen (born 1957) is a composer, instrument builder and performer. She is especially known for her performances with the long string instrument which she developed in the 1980s.

Goeyvaerts, Karel (1923–1993) was a composer, known for his early implementation of total serialism in his compositions as well as experimenting with electronic sound generating possibilities.

Haller, Hans Peter (1929–2006) was a composer and specialist in electronic music. He was the head of the *Experimentalstudio der Heinrich-Strobel-Stiftung des Südwestfunks* from 1972 to 1989. During this time, Luigi Nono* collaborated with Haller for many of his compositions using live electronics.

Hartman, Hanna (born 1961) is a sound artist and composer. In many of her works she makes use of contact microphones to build new instruments. She is active in the ensemble *Les Femmes Savantes.*

Heiniger, Wolfgang (born 1964) is a composer of live electronics and computer music, chamber music, and theatre music. In many of his works, interactive and scenic elements play an important role, often using sensor systems and electromechanical instruments.

Helmholtz, Hermann von (1821–1894) was a physician and physicist who worked on theories of vision, sensations of tone, electrodynamics and thermodynamics.

Hughes, David Edward (1831–1900) was both a professor of music and an inventor, known for inventing the microphone and the printing telegraph.

Kagel, Mauricio (1931–2008) was a composer of instrumental music as well as radio pieces and movies. In many of his pieces he focused on the theatrical aspects of music.

Kaul, Matthias (born 1949) is a composer, percussionist, and inventor of musical instruments. His compositions often include uncommon objects such as electric toothbrushes, vacuumcleaners and bicycles.

Kessler, Thomas (born 1937) is a composer, mainly for instrumental music often combined with electronics. He founded his own electronic studio in 1965 and the electronic music studio at the City of Basel Music Academy in 1987.

Kinkeldey, Otto (1878–1966) was a musicologist and music librarian who focused his research on early keyboard music and Renaissance dance.

Lerman, Richard (born 1944) is a composer and sound artist who makes intensive use of piezo-ceramic contact microphones in many of his works. He often uses this technology for making field recordings in natural environments or to amplify everyday objects.

Lockwood, Annea (born 1939) is a composer and sound artist who makes performances, such as the *Piano Transplants* (1969–1982). She is often using environmental sounds, and writes music for instruments using electronics and visual elements.

Løffler, Simon (born 1981) is a composer, using elements such as neonlights, wires and self-made mechanical sculptures.

Lucier, Alvin (born 1931) is a composer and sound artist. In his works he explores acoustic phenomena and auditory perception. He uses unusual set-ups, experimenting with technological devices in unorthodox contexts.

Maly, Valerian (born 1959) is a performance and sound artist. He develops most of his works in collaboration with Klara Schilliger (1953). Their performances and installations are often site-specific interventions. He is the artistic director of the Bone Performance Festival in Bern.

Maubrey, Benoit (born 1952) is a sound artist. He has developed many different costumes integrated electronic equipment and loudspeakers. These loudspeaker costumes are often worn by dancers during performances.

Merzbow (artist name for Masami Akita) (born 1956) is a noise musician. Having produced tape cassettes in his early career, he now mainly uses laptops to produce loud feedback and distortion noises.

Monahan, Gordon (born 1956) is a composer and sound artist who often makes use of natural forces and the environment in his work. Several of his works investigate in the role of loudspeakers in music.

Neumann, Andrea (born 1968) is a musician, playing principally inside the piano, and composer. She is a member of the ensembles *Les Femmes Savantes* and *Phosphor*.

Nono, Luigi (1924–1990) was a composer who worked with many forms of electro-acoustic music. While his earlier works were composed for tape, from the 1980s on most of his pieces were scored for instruments and live electronic processing.

Oliveros, Pauline (born 1932) is a composer and accordionist. Besides her activities in improvisation, experimental and electronic music, she also developed the 'Deep Listening' programme.

Pook, Lynn (born 1975) is an artist who has made several works based on audio-tactile experiences.

Raaijmakers, Dick (1930–2013) was a composer, sound artist, theatre maker and writer. In many of his works, microphones and loudspeakers play an important role, often used in unusual ways.

Radigue, Eliane (born 1932) is a composer of electro-acoustic music, especially with the use of the ARP 2500 synthesizer. From 2001 on, she principally composes for acoustic instruments.

Reese, Kirsten (born 1968) is a composer and sound artist. She mainly works with electro-acoustic means and many of her works are site specific and often contain performative aspects.

Reich, Steve (born 1936) is a composer, whose repertoire contains mostly compositions for instruments and amplifications. Especially during the 1960s, he experimented with the possibilities of electronic means such as tape delay.

Riemann, Hugo (1849–1919) was a music theorist. One of his most important works was the *Musik-Lexikon* (1882), an encyclopaedia of music.

Rogalsky, Matt (born 1966) is a composer, sound artist and musicologist. He has undertaken extensive research on David Tudor's *Rainforest*. He is currently a member of *Composers Inside Electronics*.

Schaeffer, Pierre (1910–1995) was a composer and writer, who worked at the French radio. He developed the idea of *musique concrète* and composed several compositions in this genre, some in collaboration with Pierre Henry.

Schroeder, Sabrina (born 1979) is a composer, often adding homemade electronics to her works for instruments. She is interested in amplifying resonances by mechanical means, without using conventional loudspeakers.

Scott de Martinville, Édouard-Léon (1817–1879) was a bookseller and printer. He invented the phonautograph in 1857.

Sonntag, Jan-Peter E.R. (born 1965) is an artist and composer. His works are often site-specific, interactive installations.

Stanic, Lara (born 1973) is a musician, performance and media artist. Many of her works focus on relationships between the performer and the efforts which have to be achieved to play the instrument.

Sterne, Jonathan (born 1970) is a scientist who has focused his research on the history and theory of sound in modernity.

Stockhausen, Karlheinz (1928–2007) was a composer, whose pieces often experiment with synthesizing electronic sounds, processing sound live or diffusing it in unusual ways. Most of these pieces were developed at the Studio for Electronic Music (WDR).

Subotnick, Morton (born 1933) is a composer of electronic music and co-founder of the San Francisco Tape Music Center. Most of his works use live electronic processing.

Tazelaar, Kees (born 1962) is a composer of electro-acoustic music. Since 2006, he is the head of the *Institute of Sonology* in The Hague. He is also active as a researcher on the history of electronic music.

Tudor, David (1926–1996) was a pianist, composer and sound artist. He made extensive use of experimental electronics in his music and developed several works with microphones and loudspeakers as crucial sound shapers.

Varèse, Edgard (1883–1965) was a composer, especially interested in rhythm and timbre, instead of pitches. He claimed that music was organized sound and composer *Poème électronique* (1957–1958) for the Philips Pavilion at the Worldfair in Brussels in 1958.

Vermeulen, Roelof (1895–1970) was an electrical engineer who worked at Philips. He has done extensive research on sound reproduction technology as well as electronic music.

Vidolin, Alvise (born 1949) is a composer, often using electronic means. He has collaborated with Luigi Nono* during many performances of Nono's compositions.

Wassermann, Ute (born 1960) is a vocal soloist and composer. She often works with what she calls techniques for 'masking' the voice with sounding objects, such as bird whistles, palate whistles or resonant objects. She is a member of *Les Femmes Savantes.*

Weissmann, Steffi (born 1967) is a performance, media, sound and video artist. Her work includes audiovisual compositions, urban interventions and interactive performances.

Wellmer, Anne (born 1966) is a composer, performer, sound and media artist. She creates performances, sound installations, live music for dance and theatre, radio art, music theatre pieces, network projects and improvisation with electronics.

Wishart, Trevor (born 1946) is a composer of mainly electronic music. He has also been written several books on this topic. His compositions often take the human voice as a starting point.

Xenakis, Iannis (1922–2001) was a composer and an architect-engineer. Mathematical models were important in his music. In several works he used special configurations of many loudspeakers.

Young, Thomas (1773–1829) was a scientist who made important contributions to research on language, musical harmony, vision, light and solid mechanics.

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