The Science of Musical Sounds

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The Science of Musical Sounds

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Preface

A long time has passed since the first time I wrote this text; the first edition was printed in 1973 and the third 1989. During these years there has been a substantial development of knowledge within the field of music acoustics. In particular, the domestication of computers has entailed great gains. For this reason the author felt it as a great privilege to revise the book. With regard to the development of knowledge and understanding in the area of music acoustics we are living in a wonderful era!

Earlier, music acoustics had to deal with rather basic problems, such as musical intervals between pure sinetones, characteristics of stationary spectra of instrument tones and other aspects of music that were far remote from the essence of experiencing music. Now musically much more burning topics can be attacked. This means that music acoustics has now the potential of fascinating a great number of musicians and other musically interested persons.

As a sign of the growth of the topic, a number of basic textbooks have appeared in recent times, starting in 1969 with J. Backus, *The Acoustical Foundations of Music;* A. H. Benade, *Fundamentals of Musical Acoustics;* D. Hall, *Musical Acoustics: An Introduction;* J. H. Pierce, *The Science of Musical Sound;* T. D. Rossing, *The Science of Sound;* and most recently, N. H. Fletcher and T. D. Rossing, *The Physics of Musical Instruments.* There is no need for another contribution from this author to this impressive collection of standard textbooks.

Rather, the author felt that a simple, popular book presenting a survey might be needed, a book that could serve as a first appetizer for musically interested people who do not want to learn more anecdotes about composers but who rather are curious to learn about new aspects of music. This book is written for such people. Where physics or mathematics appear in the text, explanations are also presented. Thus, the author's ambition and hope has been that basically everyone who is musically interested and curious to know more can enjoy reading the book.

In writing the text, I have received help from my friends and co-workers in the Music Acoustics Group at the Department of Speech Communication and Music Acoustics of the Royal Institute of Technology in Stockholm, who have read some of the chapters and offered remarks. I am also indebted to Professor Edward Carterette, editor of the series in which the book appears, for good advice and for convincing me to translate the book.

Johan Sundberg

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CHAPTER 1

Introduction

I. MUSIC ACOUSTICS

What kind of an animal is music acoustics in the disparate world of science? What does it want to achieve? What does it have to offer? These are questions that this book will answer. But at this point it might be worthwhile to sketch at least the gross contours of the answers.

Music acoustics is both old and young as a science. Early contributions were made back in the Greek Antiquity when Pythagoras wondered why certain musical intervals emerged from certain string length ratios. In our time an early important key figure was a German physician and physicist in Potsdam, Hermann von Helmholtz. In 1862 he published a thick book with a thought-provoking title, *Die Lehre von den Tonempfindungen als physiologische Grundlage der Musiktheorie (The Science of Tone Perception as a Physiological Basis for Music Theory)*. The gospel implied by this title is that music theory ultimately goes back to how our sense of hearing perceives the tones (i.e., that music theory can be based on the theory of auditory perception). This view has been preserved by several scientists in the music acoustics field, and it is frequently supported by research results, also in our time. Therefore the characteristics of our sense of hearing is an important part of music acoustics.

Hermann von Helmholtz dealt not only with the sense of hearing, but also developed theories for several music instruments that explained how they worked (i.e., how the tone is generated in the instrument). Many of his theories have not been greatly revised by later research. His descriptions of, for example, the flue organ pipe or the vibration of the bowed string are still valid. The development of theories describing the function of the various music instruments is regarded as one of the major tasks in music acoustics research. Indeed, it is a necessary task in our time. In many countries it is carried out in collaboration with the music instrument builders; they obviously need to understand how the things they manufacture function. (For comparison, just imagine the situation in which car brake manufacturers did not really understand why the brakes reduced the speed of the cars and just tried to make the brakes in the same way as their fathers did!)

In the 1930s the use of electronic technology was started in music instrument research. An American researcher of Swedish extraction, Carl Seashore, got hold of a so-called tonometer. This device allowed him to examine in detail music sounds from an acoustical point of view. He headed a research group in Iowa, which enthusiastically and productively studied performed music (e.g., intonation, tone duration, and other tone properties that musicians determine when playing). Seashore published the results in another classical book in music acoustics, *The Psychology of Music.*

Another page in the history of music acoustics was turned in the 1970s when the digital computer was domesticated, becoming an obedient research tool. This meant that much more difficult questions could be tackled than before. For example, it was possible to calculate how different bore shapes in wind instruments affected tuning and tone color. As this and other, more difficult problems could be solved, the possibilities for music acoustics to tell interesting things about music increased.

This nutshell historical survey may perhaps give an idea as to what kind of problems music acoustics used to work with and is working with at present. However, history should not determine what scientific research should be dealing with, although it often so happens, unfortunately. Rather, the questions that develop from the research results should determine activities and boundaries.

II. THE MUSIC SCIENCES

We have just seen that music acoustics is not the same as musicology, a discipline that often tends to be more or less equal to music history. In fact, music has given rise to an entire family of music sciences. To find out how music acoustics fits into this family let us start from the beginning by asking "What is music?" This question is particularly significant for the music sciences, because an answer would provide a definition of the research object.

But, unfortunately, the question is difficult to answer. Music may mean so many widely different things: the score, the sound sequences, the experiences in a listener, etc. So what is the research object of the music sciences?

Obviously, it is the music itself. But there is no convincing way of defining music. As a consequence, it is most time-consuming and rarely rewarding to try to reach a common view as to what music really is. In such situations it is often wisest to circumvent such questions with respectful silence: In most cases people know what music is, so let us refrain from trying to find a tenable scientific definition!

However, there are many tangible manifestations of the fact that music exists, as shown in Figure 1.1. Everything has a history, and music is no exception to this principle. History of music is, because of a strong tradition, the main angle of attack of traditional musicology. There is always an interaction between society and what happens in society, and again, music is no exception. Music sociology works with this aspect of music. Playing and listening to music generates experiences, reactions, behaviors, and cognitive processes, and these are the domain of music psychology. The composer creates a music score, which provides music theorists with their research object. The players generate acoustic signals, which are captured by the listener's ears. These signals are the research object of music acoustics.

Thus we find that another music science has developed around each of the many forms in which music manifests itself: musicology (i.e., music history), music theory, music psychology, music sociology, music acoustics. There are more of them, and the number will certainly increase in the future.

At first sight, some of these angles of attack may seem farfetched. But humans are by nature curious, and apparently, music experience can be enriched and enhanced by knowledge from many different fields. Perhaps the acquaintance with the stories about Beethoven's attitude toward Napoleon adds to the excitement of listening to his famous Third Symphony.

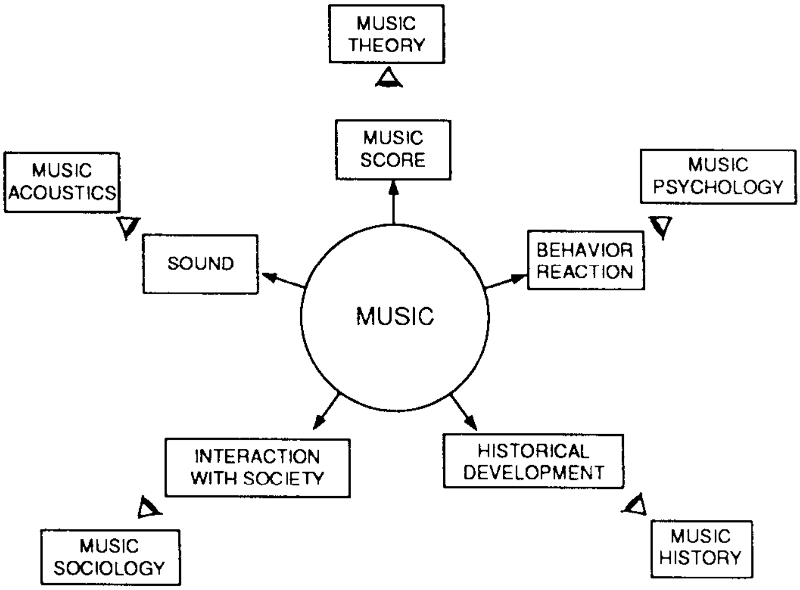

Figure 1.1 The music sciences. Music is manifested and can be observed by the researcher's examining eye from several different angles. Each of these angles has given rise to a music science. Music acoustics is one of them.

Figure 1.2 Main links in the music communication chain. It often contains more links, such as systems for recording and reproducing sound, and sometimes fewer, such as when the score or the musician is missing.

Music is transferred from composer to listener in the manner illustrated in Figure 1.2.

Note that two of the links in this chain have a particularly close relationship to music *per se:* the score and the sound. Further, although the relevant function of the three persons in the chain are mental processes, the score and the sound are the only links in the chain that are physical objects.

This is significant. It implies that the score and the sound are the only sources of information that can be submitted to a strict scientific analysis according to the model used in natural sciences (i.e., the results need not necessarily be dependent on subjective interpretations). Music acoustics analyzes the sounds and the sound sequences of music by means of the methods used in natural sciences. If essential information about music can be gained in this way, the sounds of music obviously constitute a relevant research topic.

Music acoustics is often called *musical acoustics.* The choice of labels should not be of any appreciable concern to adult brains. However, there is a reason why the name *music acoustics* is used in this book. "Musical" is an adjective referring to a gift that has been given to certain persons. This gift cannot be given to a science. This is one reason to avoid using this term. Further, the other music sciences are called music psychology, music history, music sociology, etc. In analogy with this we should start talking about musical history, musical sociology, musical psychology, etc., which sounds very awkward indeed! Hence the use of the term *music acoustics.*

III. HOW? AND WHY?

What kind of information may be gained by a study of music according to a natural sciences method? The answer must depend on what factors determine the acoustic shape of the music. At first glance we may think that the composer is the dictator who decides everything. Some more reflection will reveal a number of other contributors or contributing factors: the composer's music teachers, what kind of music taste was predominant when the piece was composed, how the composer felt when composing the piece, and so on. However, there are also a number of factors outside the composer's reach (i.e., the player's understanding of the piece, the acoustic properties of the instrument(s), the work and skill of the instrument builder). All these factors—and there are certainly more than those mentioned here—contribute to the shaping of the sound sequences created when a piece of music is being performed.

Thus, there are several, very different factors contributing to the sound sequences of music. Yet, they all share a common principle. What principle that is may be suggested by the following thought experiment.

Imagine one of the great organ pieces by J. S. Bach played first on a romantic organ from the late 19th century and then played on an authentic instrument. Imagine a piano piece by Debussy, first played on a clavichord and then on a grand piano. Imagine Rimsky-Korsakov's *Scheherazade* played first by a renaissance ensemble with shawms, viols, lutes, etc., and then by a modern symphony orchestra. When listening to the latter alternative in all these cases you are likely to feel an inner "Of course! This is the way in which this piece should be played!" But from where did this certainty originate?

The origin is, of course, not randomly developing traditions or other random factors, which, by the way, represent overly boring research objects. Instead, the origin is inherent in the human system, because music is tailored for the human capacity of perceiving and communicating by sounds. That is the common principle mentioned above, contributing to the shaping of the sound sequences of music. This adaptation to the characteristics of the human system is an overly inspiring research object, by the way.

Already the fact that the composer is a human being implies that the products carry signs of human mental effort. When composing and orchestrating, the composer consciously and unconsciously takes into account how the sounds will be perceived by the human sense of hearing. He or she would ask her- or himself things such as "What will be best here?" and "How should this be orchestrated?" The same applies to a higher or lesser degree also to musicians, instrument builders, and other people contributing to the shaping of the sound sequences. Therefore, the shape of these sound sequences contains explicit and implicit information about humans.

The title of this chapter was taken from a book with the title *Why? and How? A Key to the Natural Sciences* by Brewer, Moigno, and Parville published in Swedish first in 1890. Research following the tradition within the natural sciences should ideally answer these two questions.

The answer to the first question, "How?", is an exhaustive description of the research object. In the case of music acoustics this description does not work with the terminology typically used in music descriptions (e.g., "happily," "mystical," "determined," "light," "dark," "like birchtrees in springtime," and other expressions that attempt to describe what the piece might remind a listener of in a more or less poetic fashion. Rather, descriptions in music acoustics use acoustic terminology. Thus, they provide an acoustic description of the sound waves, containing specifications of frequencies in Hertz, of intervals between scale tones expressed as frequency ratios, of the amplitudes of sine wave components, of tone onsets, and of decays, and other temporal aspects of the sounds. To the typical reader of music books this probably appears as a most bizarre way of talking about music. The advantage is, however, that the terms can easily be defined, so that everyone has a chance to understand what they mean.

Regarding the question "Why?" the answer should explain the description emerging from the "How?" question. Let us think of an example. Why does a piano tone possess precisely its own and no other acoustic characteristics? There are several different factors that contribute. One explanation is the function of the instrument, or in other words, the theory that describes how the tone is created in the instrument. This theory explains how the material and tension in the strings, the properties of the hammer and sound board, etc., contribute to determine the properties of the tone. One important task of music acoustics is to formulate theories describing the sound generation within the instrument.

The question "Why?" also leads to other aspects of music sounds. Explanations for the sounds of music can be found not only in the instrument, but also in the properties of human hearing. The peculiarities of human auditory perception are taken into account both when the instrument is constructed and when it is played. For this reason, theory of auditory perception is another essential part of music acoustics. Of particular relevance is, of course, those types of auditory perception that occur mainly in music (e.g., the pitch, which is categorized into a limited number of scale tones; tone durations, which are categorized into certain stereotypes called *note values;* and the perception of vibrato tones).

When the scope is widened from aspects of a single instrument tone to the sound sequences of a piece of music, things obviously get more complex. Music sounds completely impossible from a musical point of view, when performed exactly as nominally specified by the music score. Musicians make music meaningful by lengthening and shortening tones, by accentuating certain tones, by making some tones louder and others softer, by inserting micro pauses between various tones, etc. By these subtle means the player makes the music interesting to listen to. These aspects of music sounds represent another important part of music acoustics.

When we listen to music it has passed at least one transmission link before it reaches our ears, namely, the acoustics of the room in which the music is played. Further, we mostly listen to recorded music (i.e., it has passed two other links: the sound recording and reproduction systems). Acoustics of music rooms and sound recording and reproduction systems are other important parts of music acoustics.

In this book the reader is invited to share the author's fascination for all these different aspects of music. Hopefully, the reading will provide a generous reward for the work.

Work? This word was not chosen by accident. Music acoustics is not as easy to digest for the typical reader of music books as the usual texts, which speak about music in a more entertaining and anecdotal way. For readers used to texts in the natural sciences area, the difficulties would be nil. The difference between these groups of readers would go back to reading habits. A pertinent piece of advice seems to be similar to what is recommended for safe driving: Never go faster than the reader, the text, and the content permit. Readers who are used to humanistic texts almost always read natural science texts far too fast, and the result then is that the text appears completely impossible to understand. If, however, the reading speed is reduced in accordance with the recommendation above, the same text may become understandable, perhaps easily understandable, and most certainly completely fascinating! With these humble words the author wishes his readers an enjoyable exploration of the science of music sounds.