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Musical composition and music acoustics: What have they to do with each other?

G Bennett

Abstract

It may seem that traditional musical composition has long gotten by with at best a rudimentary knowledge of music acoustics and that it is only with the advent of electroacoustic music that it has become important for composers to combine inspiration with scientific knowledge. After all, in electroacoustic music the the composer not only makes all the sounds for his piece but invents the grammar and syntax that relate them to each other, often relying on psychoacoustic knowledge to help him in his decisions. But in fact, as this paper shows, the findings of music acoustics have at all times in the history of Western Music determined the representational framework within which the composer formulates his ideas.

The paper first speaks briefly of some of the most important historical influences of music acoustics in shaping the way we all think about music. Second, it gives some examples from electroacoustic music to show how music acoustics has directly influenced composition. Finally, it address the question of what music acoustics might be concerned with in the future.

The relationship between composition and music acoustics is essentially quite straightforward: the composer makes things, the music acoustician investigates their acoustic structure. That the music acoustician is dependent on the composer for material to investigate is obvious. It may be less obvious that the composer is dependent on the music acoustician. I shall speak today only about the composer's dependence on music acoustics, and I shall argue that this relationship has always been significant for composition and is of great importance for music today.

The reason why music acoustics is so important for the composer is both simple and deep: music acoustics provides the representation of the sounding world with which the composer formulates his ideas. Regardless of how original a composer may think himself, he can only compose sound in an abstract way: pitches, note values, dynamic indications are some of the abstractions that Western music has used. Every composer inhabits an imaginary world of personal and private abstractions and metaphors which are essential for his work. But behind, beneath and surrounding these private metaphors are deeper abstractions which define the framework within which thoughts can be formulated, elaborated and expressed. Historically, much of this deeper level of abstraction has been based on acoustics.

This paper has three parts. First I shall speak briefly of some of the the most important historical influences of music acoustics in shaping the way we all think about music. Second, I will give some examples from contemporary music to show how music acoustics has directly influenced composition. Finally I shall speak briefly about what I would like music acoustics to be concerned with in the future.

Music acoustics begins, of course, with the Pythagoreans. The discovery that the acoustical phenomenon of consonance is related to simple numerical relations is one of the great abstractions of all time. It still colors the way we think about sound. The Pythagoreans were not very interested in sound for its own sake, however, and while they had a clear idea of pitch and interval, they had no conception of the gamut, or scale. It was Aristoxenus, a Greek music theoretician of the 4th century BC, who first considered sound as a continuum along which pitches were specific points. It is difficult to imagine that an idea so basic to our thinking had to be invented. Aritoxenus's writings, by the way, spoke only of acoustical phenomena, pitches and intervals, and used no mathematics to justify explanations.

The Pythagoreans recognized the octave as the simplest interval after the unison, but it was not until the 14th century that music theory used the octave division of the gamut as the basis of the scale; before that, two notes of the gamut an octave apart had different names and were not considered related in any musically important way. Music theory of the 14th century, however, speaks of the "identity" of two notes an octave apart. This "identity" is an acoustical phenomenon. Here music acoustics provides the basis for an abstraction—the octave scale—which has been of incalculable importance in Western music.

Basing the structure of the scale on the octave was related to the advent of polyphony. The same 14th century theoretical writings which defined the octave scale were also concerned with organizing early polyphony, called organum. The rules given for singing organum specified that the counterpoint between two voices be defined by consonant intervals. Although the definition of consonance changed over the centuries, the conception of organizing polyphonic music on the basis of acoustically simple intervals remained central to composition until the beginning of the twentieth century. Once again, a music acoustical abstraction, consonance, provided a framework for compositional thought through many centuries.

Counterpoint organizes music vertically, harmony organizes music horizontally. Already in the 16th century, music was written which sounds to our ears "harmonically organized", that is, music in which we hear that the choice of chords at one moment in a phrase implies the choice of certain other chords, and only those chords, later in the phrase. From the beginning of the 17th century on, all music was organized harmonically, but nowhere in the theoretical writings of the 17th and early 18th centuries is there any harmonic theory. It was not until 1722 that Jean-Philippe Rameau published his *Traité de l'Harmonie réduite à ses principes naturels*[1], in which he derived the major triad by Pythagorean string division and posited one and the same fundamental bass for all three inversions of the triad. This was a discovery of immense importance for music theory, because it directed theoretical investigation away from questions of interval relationship between voices, voice leading, etc. and towards the relationships between fundamental basses accounting for harmonic progression. Four years later in his book *Nouveau système de musique théorique*, Rameau discarded the idea of string division and justified his theory of the fundamental bass by the experimental and theoretical demonstration of partial tones made by the French acoustician Joseph Sauveur in 1701. Rameau was wrong or confused about lots of things (for instance the generation of minor chords or the limitations of progression of the fundamental bass), but his vision of harmony—that the relationships between fundamental basses determine harmonic progression—is still very much our own.

Perhaps the single most important date for music acoustics is 1863, the date of the publication of *Die Lehre von den Tonempfindungen als psychologische Grundlage für die Theorie der Musik* by Hermann Helmholtz[2]. It seems to me that among the many contributions Helmholtz made to music acoustics two of the most important are his proof of Ohm's law of acoustics that the ear separates complex tones into series of simple vibrations, that is, that it performs Fourier analysis, and his analysis of the relation between partial tones and timbre.

Helmholtz's influence on composition was slight until well into our century. One of the recent contributions to music acoustics which has had the greatest importance in shaping composers' representations of acoustic reality brings Helmholtz's theory up to date. This is the analysis of instrumental tones by Risset and Mathews, published in 1969[3]. Helmholtz showed that timbre of a sound is dependent on the pattern of its upper partials. Helmholtz and subsequent authors represented timbre as a fixed recipe of

[1] Rameau's theoretical works have appeared in a handsome facsimile edition: *Jean-Philippe Rameau: Complete Theoretical Writings*. E. R. Jacobi (ed.). Rome. 1967–1972. An English translation by P. Gosset was published in 1971.

[2] Helmholtz saw *Die Lehre* through four editions. Alexander J. Ellis translated the third German edition (1870) into English in 1875; he adapted his second edition (1885) to Helmholtz's fourth and final edition of the German text. Alexander's translation was reprinted in 1954 as *On the Sensations of Tone as a Physiological Basis for the Theory of Music* by Dover Publications.

[3] Risset, J.-C. and M.V. Mathews. Analysis of musical instrument tones. *Physics Today* 22(2), 23–40. 1969.

[4] Here four of the major papers: —Schroeder, M.R. Improved quasi-stereophony and colorless artificial reverberation. *Journal of the Acoustical Society of America* 33, 1061. 1961. —Schroeder, M.R. Digital simulation of sound transmission in reverberant spaces (part 1). *Journal of the Audio Engineering Society 10(3), 219–223.* 1962. —Schroeder, M.R. Natural sounding artificial reverberation. *Journal of the Acoustical Society of America* 47(2), 424–431. 1970. —Schroeder, M.R., D. Gottlob and K.F. Siebrasse. Comparative study of European concert halls. *Journal of the Acoustical Society of America* 56, 1195–1201. 1974.

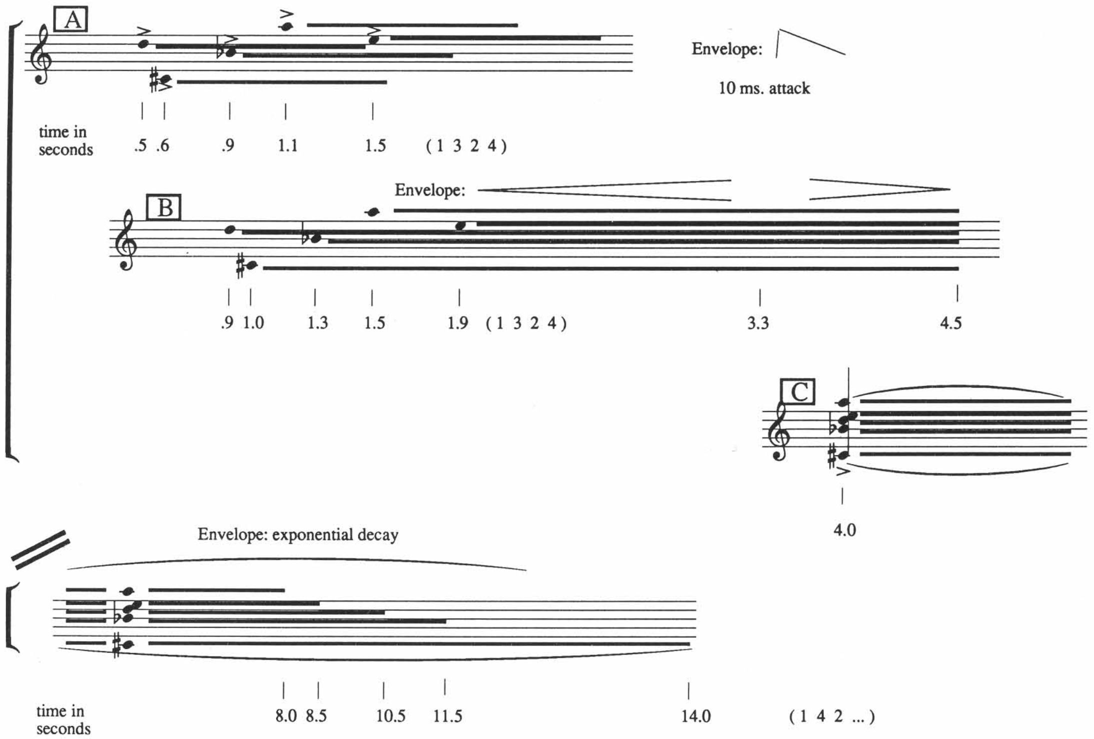

Figure 1

Figure 1: Jean-Claude Risset: Mutations. *Transcription of the the first 14 seconds, showing for each of the first three sound complexes (A, B and C) the entrance and end times of each note. The numbers in parentheses show the proportional structure of the time intervals between successive attacks.*

partials, so to speak a snapshot of partial frequencies with fixed amplitudes. Risset and Mathews showed how the partials of a trumpet tone change amplitude as a function of time in an ordered way, thus obliging us to think of timbre as a dynamic, three-dimensional phenomenon and not a static, two-dimensional one. This discovery must be regarded as one of the most important findings in recent music acoustics.

A final very important development in music acoustics concerns the simulation of reverberant spaces beginning with the classic articles by Manfred Schroeder on artificial reverberation in 1961 and extending to Schroeder's computer simulations of the acoustics of several European concert halls in 1974[4]. Schroeder's work has taken an important step in freeing music from its dependence on the physical surroundings of its performance and has influenced deeply contemporary composition's view of acoustical space.

This concludes the first part of my paper. I would now like to give you a few examples of how music acoustics has influenced contemporary composition. These examples will be taken from the field of computer music. There, where the composer is responsible for shaping each sound, dependency on acoustic knowledge is especially great; I think one can see most clearly there the importance of acoustic representational models for composition. The importance of music acoustic representation for instrumental composition seems to me equally great, but instrumental composers are generally less concerned with the newest developments in music acoustics and usually rely on what has percolated down into common knowledge.

Let me speak first about three important sound synthesis techniques, all of which depend intimately upon music acoustical knowledge. The first is the most basic and at the same time most general synthesis technique, additive synthesis. Here the individual partials of the sounds are synthesized separately and added together to form complex sounds. Obviously, the use of this technique goes back to Helmholtz's proof of Ohm's law of acoustics. The first example is by Jean-Claude Risset from a piece composed in 1969, *Mutations* (Sound Example 1)[5].

A transcription of the beginning of the piece shows three occurrences of the same harmony: first (sound A) as five notes with percussive rise times and short (0.6 second) decays, then (sound B) as five notes with the same rhythm of entrance and long envelopes, all with crescendo to time 3.3 seconds and a decrescendo to time 4.5 seconds, then at 4 seconds a gong-like sound (sound C) consisting of the same pitches, each decaying exponentially at a rate inversely proportional to its frequency. Risset conceives of the gong sound as a "timbre echo" of the first two. Here the traditional distinction between pitch as timbre is blurred, a theme of much of Risset's computer music. In this case, musical thinking is profoundly related to acoustic knowledge.

A second important area of synthesis which is directly related to music acoustical knowledge is represented by all those techniques allowing the composer to work in the pitch domain. I shall use as an example the software instrument called the Phase Vocoder, developed by Mark Dolson[6]. In this instrument, the Fourier Transform is performed repeatedly on existing sounds, yielding a kind of three-dimensional Fourier Transform; this analysis data can be manipulated by the composer and then used to resynthesize new sounds. This intuitively straightforward (but computationally demanding) technique allows, among other things, independent treatment of pitch and duration: sounds can be transposed without changing their duration or shortened or lengthened without changing their pitch.

Sound example 2 illustrates time expansion by a factor of thirty of a short phrase played by a flute. The music is from *Transfigured Wind II* by Roger Reynolds[7]. You hear the normal sound of the flute (played live in the performance of the piece) followed by the expansion.

Sound Example 3 illustrates an example of Phase Vocoder synthesis in which a vocal sound is transformed into the angry hum of a swarm of bees and back again. Here the spectral data of the first sound is gradually interpolated to the spectral data of the bees' hum. The interpolated data is then used to synthesize the metamorphosis of one sound to the other. This example is from an electroacoustic piece by Trevor Wishart, *Vox 5*[8]. The technique employed here is derived directly from the representational framework given us by Helmholtz and Risset. I would argue that the intuitive ease of use of the Phase Vocoder has to do with its realization of a conceptual model derived from music acoustics.

You may ask whether all synthesis techniques are not closely related to models dependent on music acoustic research. Frequency modulation seems to me a good example of a technique which was not developed from a representation of acoustical processes. In consequence, I believe, frequency modulation has always proven difficult for composers to use intuitively. In particular, the symmetrical evolution of the sidebands about the carrier frequency and the distribution of energy according to Bessel functions make frequency modulation unlike models of natural acoustic reality.

The third synthesis example is from a recent piece of my own using a technique of formant synthesis developed by Xavier Rodet and me, with a great deal of assistance from Johan Sundberg, at IRCAM in the late 1970's[9]. The synthesis algorithm is very different from additive synthesis and was originally based on speech synthesis models proposed by Gunnar Fant of the KTH at Stockholm and modified on the basis of acoustic measurements of human singing voices. Formant synthesis proved to be capable of producing a wide variety of different sounds besides singing and has been widely used in computer music. Sound Example 4 is taken from a piece called

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[5] *Risset.* INA C 1003 (Harmonia Mundi France).

[6] See Dolson, M. The Phase Vocoder: A Tutorial. *Computer Music Journal*, Winter 1987, and Dolson, M. Fourier-Transform-Based Timbral Manipulations. In Mathews, M.V. and J.R. Pierce. *Current Directions in Computer Music Research*, 105–112. Cambridge (Mass.). 1989.

[7] Roger Reynolds: *Whispers out of time* and Transfigured *Wind II*. New World Records 80401–2.

[8] Trevor Wishart:*Vox*. Virgin Classics VC 7 91108–2 (*Vox 5* is also on:*Computer Music Currents 4*. WER 2024–50 (Wergo).

[9] Rodet, X. and L.-L. Delatre. Time-domain speech synthesis-by-rules using a flexible and fast signal management system. In *Proceedings of the ICASSP 1979*. Washington, DC. 1979. Rodet, X., Y. Potard and J.-B. Barrière. The CHANT project: From the synthesis of the singing voice to synthesis in general. *Computer Music Journal 8(3)*, 15–31. 1984. Bennett, G. and Rodet, X. Synthesis of the singing voice. In Mathews, M.V. and J.R. Pierce. *Current Directions in Computer Music Research*, 19–44. Cambridge (Mass.). 1989.

Figure 2a.

Figure 2a: Jonathan Harvey: Mortuos plango, vivos voco. *The first 24 partial tones of the great bell of Winchester Cathedral with the striking note "f".*

Figure 2b.

Relative durations of each section: 1 1/3 3/4 3/8 1/2 3/10 (5 : 12)

1 : (2)

Figure 2b: Jonathan Harvey: Mortuos plango, vivos voco. *The central pitches of the eight sections of the piece.The durations of the sections are inversely proportional to the frequency of the central pitch.*

Rainstick, named after a Central American instrument made of bamboo used to conjure rain. Here a singing voice dissolves into its component formants, each of which imitates the sound of the rainstick. The representational framework is given by knowledge of the acoustics of the singing voice; this knowledge allowed me to imagine (and realize) a musical situation which would have been impossible otherwise.

Sound synthesis is clearly one field of contemporary music which is very dependent on music acoustics for its musical metaphors as well as for specific knowledge. Another field is the treatment of sound. Two sound examples illustrate the spatialization of sound. In the first, realized by Kendall, Martens and Decker at Northwestern University in Chicago, footsteps were recorded monophonically and processed to simulate movement in space (Sound Example 5)[10]. This technique makes use on the one hand of work that goes back to Schroeder's studies of artificial reverberation and of music acoustic studies of spatial audition on the other. The existence of such techniques allows composers to incorporate the notion of imaginary spaces into their compositions to a degree not before possible. Sound Example 6 is from the composition *Northern Migrations* by Shawn Decker. Here the movement of the sound is an important part of the compositional plan.

The next sound example is more complex. Here music acoustics provides the frame of reference for an entire composition, *Mortuos plango, vivos voco,* a piece for tape by Jonathan Harvey[11]. In his piece, Harvey uses two different materials, a boy's singing voice and the great bell of Winchester Cathedral, whose sound he analyzed.

Figure 2a shows the principle harmonics of the bell, together with the striking tone, an "f" which does not appear in the harmonic series. Each harmonic has its own amplitude envelope; higher partials die out sooner. This relationship between pitch and duration is central to the piece. Each of the piece's eight sections has a central pitch taken

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[10] Kendall, G.S., W.L.Martens and S.L.Decker. Spatial reverberation. In Mathews, M.V. and J.R. Pierce. *Current Directions in Computer Music Research,* 65–87. Cambridge (Mass.). 1989.

[11] *Computer Music Currents 5.* WER 2025–2 (Wergo). See also: Harvey, J. Mortuos plango, vivos voco: a realization at IRCAM. *Contemporary Music Journal* 5,4. 1981, and Harvey, J. The mirror of ambiguity. In Emmerson, S. (ed.). *The Language of Electroacoustic Music.* London. 1986.

from the lower partials of the bell, as shown in Figure 2b; the duration of the first six sections is inversely proportional to the central pitch of each section. Recordings of the boy's voice are used and transformed, but most of the singing voices are synthesized using the formant-synthesis technique described above. Bell sounds can take on amplitude envelopes and partial frequencies from the singing voice, singing voices can have partials tuned to the non-harmonic proportions of the bell and can take the amplitude envelopes of the bell's partials. Sound Example 7 illustrates the beginning of the piece, where the pitch relationships and the temporal proportions are first presented. You hear first all the partials of the bell, then passages with sung and synthesized tones, using primarily these main pitches. All temporal aspects of each note are treated in inverse relation to the pitch of the note: durations are shorter for higher notes, longer for lower notes.This is example of a composition which at every level, both in the microstructure of the synthesis and at the level of formal articulation, is shaped by a vision of the relationship between sound and time which comes straight from music acoustics.

I imagine that in the long run good science and good musical thinking go together; Rameau's vision of the fundamental bass of harmony, supported by the hard mathematics of Sauveur's demonstrations of the existence of partial tones seems to me a very moving example of good science and good musical thought. But in the short run, the relationship between scientific thought and musical thought is often much more complex than my examples might suggest. Rameau had read the science of his time, and his imagination had been molded by it. But the *Traité* is more like a poem than a scientific book—the elliptic, open syntax and the often labyrinthine sentences and paragraphs of the *Traité* show how Rameau is proceeding intuitively, feeling his way down corridors of thought no one had traversed before him. The science he had absorbed worked in some mysterious way on his conscious and unconscious thinking, allowing him to formulate an idea no one had had before. This is the central point of my paper: we musicians are dependent on good science for the molding of our imagination, even if the relationship is not always direct, and even if you scientists may not always recognize your work in the results of our imaginative thinking.

In the third part of this paper I would like to speak briefly about my expectations for music acoustics. They are not technical or scientific; it is not for me to speak about the future orientation of a field whose science gets on very well without me. I view music acoustics as part of music theory, and it is in the advancement of music theory that I expect important contributions from music acoustics.

There are two great problems in music theory today, the problem of musical analysis and the problem of the history of music. The question of musical analysis seems to me by far the more important because its solution has relevance for the understanding of the history of music. I believe that music acoustics has a vital contribution to make to the solution of both of these problems.

The problem of musical analysis is that there are no relevant analytical tools for dealing in a general way with contemporary music. Traditionally a score reveals everything important about a composition, except of course the sensuous immediacy of performance. Experienced readers can analyze scores and learn a great deal about a piece's inner structure, its poetic intention, etc. But most of the analytical tools in common use today date from the nineteenth century and contain presuppositions about harmony, melody, rhythm and aesthetic intention which have been irrelevant for nearly 100 years. Contemporary music has become an oral culture—composers can speak about what they do, but only in an anecdotal way. An analysis of a contemporary score without knowledge of how the piece was composed is usually very meager. This is especially the case for electroacoustic music, for which there are no scores.

But musical analysis is extraordinarily important, not only for composition but for musical life in general. Analysis renders objective what otherwise remains largely subjective; analysis is the mirror which makes reflection about one's own activity possible. Without analysis and reflection, everything one does remains anecdotal, unique, without reference to past or future. Music theory desperately needs a renewal of the analytical language to include contemporary music. Besides providing an objective vocabulary with which to study the music of this century, a renewed analytical language would allow new insight into the music of the past. Because this renewal must take account of music existing only as auditory experience, analytical criteria must be found which are at least partially acoustical in nature. The definition of these criteria seems to me an important task for music acoustics.

The second problem, that of the history of music, is related, I believe, to the first. The problem is that in traditional music theory there are virtually no explanations of the mechanisms of the evolution of the musical language. In my day-to-day teaching of harmony and counterpoint I spend a great deal of time working with historical styles: motets in the style of Palestrina, fugues in the style of Bach. I have long been struck by the fact that in their exercises gifted students often find very interesting and very musical solutions which I must judge wrong, because historically the musical language went in a different direction. It is as though the students explore parallel routes which history discarded, or never discovered. I dream of a music history which would demonstrate the mechanisms of selection working upon the development of the musical language. To the extent that auditory phenomena must be taken into account—and I believe that their inclusion is central to any discussion of musical evolution—music acoustics has a very important role to play in defining a new vision of the history of music.

I have not spoken much about the importance for musical composition of the myriad individual achievements, discoveries and inventions of contemporary music acoustics and have insisted so strongly on the importance of the representative framework which the sum of this activity provides. Most composers are quite resourceful and will happily make music out of anything they find lying around, and of course that includes techniques and inventions coming from your work. But the real nature of the relationship between musicians and music acousticians seems to me to be this: we musicians formulate mysteries in sound; you music acousticians help us to understand what we have done. From our mysteries you distill certainty; from your certainty we spin our mysteries.