Aural atoms and structures: From electroacoustic ear training to analysis and back again

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Abstract

Analysis in electroacoustics (Ea) is an aural necessity. We analyse to understand what we hear, but we also need trained ears in order to analyse, because analysis requires detailed content, which in Ea is available mostly in sonic forms (i.e. not in music scores). This interdependence of analysis and ear training has been the basis of Ea aural training courses at Concordia University in Montreal, which I have been developing for the past decade. These courses begin with an atomistic approach, which trains students in breaking aural stimuli into the smallest possible parts (aural atoms) and thus extracting more evidence for analysis from them. Once the students' ears become focused and detailed, the courses proceed with a synergistic analytical approach, aimed at training students to assemble and integrate aural atoms into synergetic structures – perceivable higher-level units that have properties that are different from those of their parts. This structuring process provides additional evidence from higher hierarchical levels of organization. Precision, detail, and organization thus come from a spiralling rigorous practice of ear training and analysis back and forth.

Introduction

We analyse electroacoustic (Ea) music to hear it better and to understand what we hear. But we also need to hear better in order to analyse, because content for analysis in Ea contexts is typically available exclusively in sonic forms – not written musical scores. With inspiration rooted in auditory scene analysis (ASA) (see Bregman, 1990), the interdependence of hearing and analysis has been the basis of an Ea aural training method at Concordia University in Montreal, which I have been developing for the past decade. Given in aural training classes twice-a-week for two years, this method serves as a foundational aural training platform for music students who major in Ea studies. These aural training courses begin with an atomistic approach, which trains students in segmenting aural stimuli into the smallest possible parts (*aural atoms*) and extracting more information from them. Once the students' hearing becomes focused and detailed, the courses proceed with a synergistic analytical approach, aimed at training students to assemble and integrate aural atoms into *synergetic structures* – perceivable higher-level units that have properties that are different from those of their parts. As listeners become skilled in this structural hearing, they develop the ability to switch among different segmentation/integration schemes and to define and perceptually hypothesize new aural atoms and synergetic structures. This ability allows them to extract increased amounts of information about sound parameters, structures, and relationships, which can yield new insights into sound organization. In this article I introduce the principles of this analytical ear training mechanism in the context of Ea studies.

Primacy of the Ear

Aural perception is primary in Ea practice. Fennelly (1967: 79) explains, "with the absence of available musical scores, the aural experience is the single point of departure for the analysis of electronic music." Several other analysts have also raised the problem of the missing, hard-to-get, or incomplete musical score (i.e. precise instructions to performers or technicians who realize the music) in Ea music (see Stroppa, 1984; Camilleri and Smalley, 1998; Bossis, 2006; Clarke, 2012). Delalande (1998: 14) adds that Ea music analysis "presents the analyst with all problems simultaneously: no score, no system, and no 'pre-segmented' discrete units like notes." But the aural nature of analysis in Ea is rooted more deeply; the primacy of the ear has been a foundational principle since the early history of Ea practice. Schaeffer (1957) sketched a research method, in which he posited that new aural potentialities – not technological ones – were the most revolutionary aspect of *musique concrète*. This is not to say that technological innovation has not been central to the field, but that its role has been most significant in provoking sonic innovations by Ea composers, performers, and tinkerers; and that these sonic innovations have lead to aural innovations (i.e. new instruments lead to new sounds, which can lead to new ways of hearing).

The lacks of musical scores and theoretical and methodical standardization are likely products – not causes – of the nature of Ea practice: The field's rapid evolution and drive for technological and aural innovation makes standardization difficult, and possibly unnecessary; and the lack of musical scores is due to the primarily aural nature of acousmatic experimentation – as well as the integration of the composer and performer roles, which annuls the need for performance scores.

Ear Training and Analysis Back and Forth

A brief overview of the definitions and purpose(s) of musical analysis may provide context for understanding the interdependence between analysis and aural training in Ea. According to Bent (1987: 528), music analysis is "the means of answering directly the question 'how does it [the music] work?" Pople (2002: 18) suggests that the answer to Bent's question depends on analysts' interpretations, and proposes that analysis is fundamentally "an evidence based investigation." He suggests that as the paradigms of knowledge shift, evidence may be "sought in places that weren't evidential before" (Pople, 2002: 20). The term analysis comes from the Greek *ana-luo*, which means to dissolve (Stroppa, 1984), suggesting the process of breaking something into component parts. However, listing components cannot be considered a complete analysis without an element of structure, because parts alone do not tell us how the whole works. One recurring analytical principle in the literature involves the examination of units of analysis in the context of larger structures. Green (1965: 70) proposes that "analysis is the separation of a whole into its parts and the exploration of the relationship of these parts to the whole and to each other." Similarly, Bent (1987: 1) poses that analysis is achieved through "the resolution of musical structure into relatively simpler constituent elements, and the investigation of the functions of those elements within that structure." In summary, according to these sources analysis is concerned with units, hierarchically organized structures, and relationships.

Aurally centred analysis and aural training are interdependent because analysis depends on the extraction of precise auditory information (improved by training) and because aural training expands to new skills with new audible parameters added by higher-level synergetic structures. To illustrate this principle, I will borrow an analogy from the tonal/metric domain, because it stands on firmer theoretical grounds than Ea structures. For example, the ability to differentiate between melodic perfect fourths and perfect fifths is required for discriminating between melodic motifs made from scale degrees 1-4-1 and 1-5-1 (assuming all other parameters are identical). But perceiving melodic motifs demands more than interval discrimination skills. Melodic motifs are not intervallic sequences – or even sequences of intervals, directions, and durations – because hierarchical structuring in music is synergistic. Structural units are not the sum of their parts; they have properties and effects other than those of their parts. The most important feature of synergistic structuring is that parts become wholes – ontological units that are different from their parts, with different properties. The oneness of the whole and its emergent properties depend on a purposeful organization (Corning, 2002).

For example, melodic motifs – unlike intervals – may have a contour-driven flow (such as an upward motion followed by a downward motion). Moreover, in the context of a higher synergetic structure – say, a phrase – two identical motifs may be discernible by compositional function, such as one being a call and the other a response. Every structural level has its own parameters. Nevertheless, to perceive higher-level relationships with precision, lower-level discrimination skills are required; for instance, where one might have heard the call and response of the previous example as identical units, a more precise listener could, perhaps, recognize that the response's concluding note was slightly longer. But lower-level discrimination skills are insufficient on their own. Listening must also involve parameters that emerge from higher-level synergetic structures. To use a linguistic analogy, one cannot learn words and sentences with only the skill to identify letters.

Admittedly, this example is a simplification of the aural experience because it isolates parameters from their complex network of relationships with other parameters. However, the benefit of the atomistic/synergistic approach is that it promotes detailed listening and that it allows the aural learner to build a conscious perceptual network of relationships, by experiencing one synergistic leap (i.e. hearing a higher level structure as a unit) at a time. The emphasis on consciousness is central here, because having a conscious relationship with a structure and its parts improves navigability. Extracting information from previously "travelled" structures becomes like finding an address in familiar streets. Hierarchical organizations may be structured and perceived with any definable atom at any structural level, be it expression parameters (e.g. dynamics, articulation, tempo, note durations, timbral instructions, ornamentation, etc.), grammatical parameters (tonal functions, metric weight, etc.), textural elements, and any other audible unit. I posit that the more hierarchies we perceive, the greater the amount of analytical evidence that surfaces, and the broader, deeper, more detailed, more precise, and more flexible our hearing skills become.

Considering notes as atomic units in tonal music analysis is quite an intuitive choice, and analysts often consider motifs as basic synergetic units of meaning in music[1]. For the Ea analyst, Schaeffer's *objet sonore* may be the most familiar point of reference for discussion.

[1] Nevertheless, the subject of music segmentation is rich in subjective interpretations and ambiguities, due to the shortcomings of common language in describing the variety of musical segments with precision. See Nattier (1973) and Monelle (1992).

Like the aural atom, the *objet sonore* is a basic perceptual unit, though Schaeffer (1966) defines it specifically as the product of phenomenological reduction – *écoute réduite*. Contrarily, the concept of aural atoms is not married to any philosophy or system, but only to the principle that aural atoms are perceptual components of larger perceptual synergetic structures.

A balanced *objet sonore* according to Schaeffer's *Tableau récapitulatif de la typologie* (TARTYP) is not too short (a micro-object) or too long (a macro object) (Chion, 1983; Palombini, 1993). For analytical purposes, Delalande (1998: 17) recommends repeated listenings "to distinguish the units (neither too large nor too small) which make up the music." Roads (2001: 3) defines sound object as "a basic unit of musical structure, generalizing the traditional concept of note to include complex and mutating sound events on a time scale ranging from a fraction of a second to several seconds." He places it on a temporal scale between the mesostructure ("divisions of form", Roads, 2001: 3) and the microstructure ("sound particles […] [at] the threshold of auditory perception", Roads, 2001: 4). The atom and synergetic structure concepts, on the other hand, do not denote objects, but functions. An aural atom may be any part from which structures are built synergistically. A synergistic structure is a whole made from atomic parts, which exhibits properties that are different from those of its parts. The dichotomy between the perception of atoms and structures is a matter of perspective. We may focus our attention on an aural unit (say, a short granular tone) while aurally perceiving it as a structure made from atoms (grains), or as an atom in a structure (e.g. an iterative texture of granular tones). We may alternate our attention between structural levels and extract hierarchically-layered analytical information. In my experience with Ea aural training students, the speed with which this attentional alternation is accomplished increases with training.

New creative practices in Ea (e.g. live, improvisatory electroacoustics, laptop orchestras, live coding, algorithmic designs, various soundscape practices, and Ea practices within interdisciplinary settings, among others) entail new perceptual practices. For Ea ear training purposes, I propose that no unit should be considered too small. Atoms should begin with the smallest perceivable units – right at the threshold of perception. Ear training can start by training discrimination at the threshold of hearing – also known as *just noticeable difference* (JND) in perception studies – to increase listeners' sensitivity (i.e. to lower their JNDs) and build hierarchically upwards from there. This approach is based on the premise that more sensitive hearing produces more detail and better precision for the analytical process. The increased precision and amount of detail allows perceptual formation of higher-level synergetic structures with new aural parameters and relationships (e.g. integration, segregation, fusion, similarity, contrast, causality, correlation, balance, augmentation, diminution, proximity, gravity, reference, diverging, converging, and others). Recognizing and discriminating among these new parameters and relationships requires new skills to be trained. Precision, detail, and organization come from a spiralling rigorous practice of ear training and analysis back and forth.

Ea Aural Training Strategies

Ea aural training at Concordia University first focuses on increasing the amount of perceived aural details and later on constructing higher-level aural structures.[2] The first pedagogical stage involves atomistic training, which is designed to provide a higher aural resolution and increased detail by improving three foundational skills:

1. streaming (breaking the overall aural stimuli into individual streams – or aural events – which may be at first associated with voices or objects in a mix);
2. microtemporal segmentation (breaking a stream into smaller temporal units);
3. JND discrimination (the ability to distinguish minute variations).

The second pedagogical stage involves synergistic training, in which students are encouraged to switch their focus gradually towards higher-level synergetic structures. The breadth and variety in Ea and the lack of common musical syntax allow for many analytical approaches and parameters of focus in higher-level units. These units may include *objets sonores*, multilayered sounds, groups, clouds, gestures, textures, sections, forms, and others.

Atomistic training

Atomistic ear training is focused on lowering perceptual thresholds by guiding the focus of attention towards certain features or parameters of aural stimuli. Researchers have shown evidence that attention plays a role in auditory streaming (Carlyon et al., 2001; Thompson, Carlyon and Cusack, 2011), segmentation (Toro, Sinnett and Soto-Faraco, 2005; Morillon, Schroeder and Wyart, 2014), and various auditory discrimination tasks (van Wassenhove and Nagarajan, 2007; Fritz et al., 2007); and that auditory attention is trainable (Soveri et al., 2013). Atomistic ear training exercises may include:

1. discrimination and seriation drills, in which students focus on identifying and ordering JND variations in aural parameters (e.g. click durations, delay times, microtuning, loudness, harmonicity/inharmonicity, spatial features, and others);
2. hunting drills, in which students capture or count specific items in a sequence of similar items (e.g. hunting for a specific pitch, timbre, vowel, click, spatial position, etc. in a sequence) – thus training their temporal segmentation; and
3. streaming drills, isolating voices or certain parts of a continuous sonic mixture. Streaming exercises include discrimination and seriation and hunting drills that are done with a distracting element, such as background music or noise, or through identification drills of frequency boosts and attenuations, which force the students to listen intently to parts of the spectrum. As one student testified in a frequency-attenuation homework report, “I was able to stream the individual sound beforehand and predict its attenuation”.[3]

Synergistic training

The increased aural detail resulting from atomistic training provides more possibilities, more ‘lenses’ to perceive what goes on in the sound of a piece and collect more evidence for organizing the music hierarchically. For example, once training allows us to perceive minute microtonal variations (say, 3 cents), we may be able to identify a subtle vibrato in what we

[2] For further details on the pedagogical and educational strategies of this ear training method see Tsabary (2012, 2013).

[3] A quote from a homework practice report from data gathered for my doctoral dissertation (Tsabary, 2013).

previously heard as a stable tone. We may, then, define a single up-and-down pitch motion (an inverted parabola) as an aural atom and recognize vibrato patterns based on variations in rate and intensity. We could, hypothetically, recognize that the vibrato rate increases and decreases slowly at a larger-scale parabolic motion, and so on. Again, synergies emerge with new parameters and relationships due to increased discrimination ability at the atomic level. Ear training drills in this stage have included:

1. compositional studies of spectromorphological motion types, relationships, and textures; and
2. analyses of perceptual processes, relationships, textures, and form.

Attentional regulation

In addition to evidence gathering, atomistic and synergistic training strengthen *attentional regulation* – the overarching ability to direct attention selectively between perceptual objects – which has been shown to improve with repeated practice (Rueda et al., 2007; Lutz et al., 2008). In other words, navigating aurally across parameters and structural levels trains and improves the navigation's intentionality and speed and can accelerate the process of evidence gathering and synergistic structuring. The ability to switch attentional focus across hierarchical levels and parameters also surfaced as the most important skill for Ea aural training in a survey I conducted among 15 Ea experts, which was focused on the question "which aural skills are necessary for composing, performing, and understanding EA music?" (Tsabary, 2009: 300).

With increased speed and precision of selective attention, listeners become capable of making connections across hierarchical levels and parameters in real time. At Concordia, this skill has been further tested and trained with spectrogram matching exercises, which demand attention to, and memory of, parameters at multiple structural levels in one listening. In these exercises, students first listen to a musical excerpt (30-60 second long) and analyze it for features that could stand out in a spectrogram image. Once they finish listening, they are given several spectrogram examples from which they have to choose the correct one. The spectrograms are typically from similar and repeated sections of a piece and may differ slightly in a few parameters at any structural level (e.g. a certain reverb tail is longer, a certain line is octave-doubled, a certain texture appears for a shorter period, etc.). Since listeners cannot know in advance which feature would be the most distinct, they have to hunt for several of them, which requires a constant change of focus and a strategic, prioritized memorization of features and relationships. In my experience, training with this form of exercise has produced an increase in students' ability and speed of switching their focus among structural levels and in identifying and memorizing distinct features. However, this finding requires more study.

Individualized Learning

In-class JND discrimination ear-training drills at Concordia have focused primarily on amplitude, frequency, spectral profile, microtime, and space, and synergistic structuring exercises have included foci on process, gesture, motion, relationships, texture, and form. While the specific examples used in class and the teacher's approach undoubtedly influence students' perception, they are presented as examples through which the logic of atoms and synergistic structuring is communicated and trained. As students become more skilled at controlling their focus (attentional regulation), they are encouraged to experiment by devising their own hierarchical perceptual systems – to define the atoms that they find interesting or meaningful and form emerging structures in their perceptions. The synergistic structures that emerge in this process depend strongly on students' atomic definitions; however, the structures' potential variety among individuals is exponentially larger than that of atomic level units, due to combinatorial growth in higher hierarchical levels.

In my experience, students understand the atomistic concept and witness a radical change in their micro-aural skills fairly quickly, but take longer and need more guidance in making the leap to perceiving and constructing higher-level structures. This may be related to the nature of our ability to process and organize auditory information, which according to Bregman (1990) depends on two hierarchically-arranged mechanisms: The first mechanism parses basic auditory information preattentively (automatically), and the second organizes patterns based on existing schema – that is to say that it depends on previous experience in organizing auditory patterns. Other recent studies show evidence that prior experience and its effects on the auditory brainstem speed up auditory learning of sonic patterns and combinations (Skoe et al., 2015; Skoe et al., 2013). This evidence does not suggest that when we hear complex patterns we process them in exactly the same manner as we did in the past, but that our perception depends on "an interaction between familiarity, implicit statistical learning, and brainstem physiology" (Skoe et al., 2015: 138). Thankfully, the field of Ea includes various analytical methods, hearing approaches, and systems of thought[4] that can be taught and practiced in order to build experience in structural sound organization. For this reason, students at Concordia learn aspects of Schaeffer's TARTYP (1966) and Smalley's Spectromorphology (1986) before they are asked to discover and define their own synergistic structures.

Multiple Perspectives

The analytical methods, hearing approaches, and systems of thought mentioned above (and others) had defining roles in the evolution of Ea studies and predominantly involve synergistic structuring. Nevertheless, none of these approaches has become standardized as "Ea music theory", in the manner that tonal music theory has had with Rameau's treatise (1722). This fact does not reflect negatively on the merits of these studies; on the contrary, it illuminates the needlessness of standardization in Ea at large, due to the field's breadth and its innovative nature. The lack of theoretical and methodical standardization is a positive attribute that supports the field's meteoric evolution because it allows Ea researchers and creators to innovate their practice flexibly, unchained by convention. The contrast between composing for conventional instruments and creating instruments as part of the composition process (as is common in Ea music, primarily in the digital domain) (See Jordà, 2005; Magnusson, 2010; Drummond, 2009), serves as a simple example of this flexibility of innovation.

The greater the number of cohesive approaches and angles of exploration of Ea listening and analytical thought, the more aural evidence we can gather and integrate. Each approach is a perceptual filter that explores certain kinds of parameters and structures. While theoretical systems may be detailed, deep, and precise, they cannot be comprehensive because they are not able to cover other points of view. By definition, what makes an approach cohesive is the

[4] Examples of such analytical methods, hearing approaches, and systems of thought are presented in Schaeffer (1966), Chion (1983), Delalande (1998; 2013), Smalley (1986), Thoresen (2010), Roy (2000), Normandeau (2010), Roads (2001), Oliveros (2005), Schafer (1967), and others.

internal logic that holds it together. But other cohesive points of view can provide additional evidence to integrate towards making new connections and generating a more detailed picture and additional layers of organization. Systems are likely to overlap in many ways, but their foci and logics may be arranged differently and generate different data.

As an analogy, consider how mapping in earth sciences (e.g. geology, topography, hydrology) focuses on some information while strategically ignoring other interdependent information in order to maintain purpose and detail. To illustrate, consider how the movement of water (studied in hydrology) over time has an abrasive effect on rock shapes (studied in lithology), and may cause rockslides, which change rock distribution (structural geology), which may create dams and change water distribution (back to hydrology), and so forth. The accumulation of the detailed information from each filtered mapping-process can assist in building a deeper understanding at higher structural levels across sciences. Nonetheless, the relationships in this example may be oversimplified, and these forces are only a tiny fraction of a complex network of forces that could be studied (atomistically and structurally).

I propose that the complexity of aural perception is potentially of a similar configuration, where every definable aural parameter – from an existing or new system – can be perceptually filtered and studied atomistically and structurally. For example, one may explore an Ea composition by atomizing and mapping all the audible attack types, reverb tails, or dynamic peaks. One may focus on long sounds and map their trajectory, or may choose to identify rhythmic elements and map their distribution. Or perhaps one could listen differently every time and create multiple maps and explore their interrelationships. The question to ask about music analysis in this context is, thus, not 'how does it work?,' but more elaborately, "what is one way in which it works? What is another? And another... and what is one way in which all or some of the previous answers work together? And what is another way? and so forth…" All of this while maintaining a strong attachment to perception (i.e. hearing, not just theorizing), with precision, detail, and atomistic/synergistic structural coherence.

Aural Hypotheses

I would like to preface this section with a personal recollection. During a snowy drive to work, I listened to the repetitious squeak of the icy wipers on my windshield and initially identified the squeaks as downward pitch gestures (approximately a minor seventh wide). Though quite interesting, I quickly sought a musical development and decided to break the squeaks into two parts: the downward gesture and the arrival tone, which quickly became call and response – despite their acoustic continuity. I explored relationships between the calls and then between the responses and noted variations in pitch, durations, curves, amplitudes, timbres, and so forth. Soon, another voice emerged – a concurrent smaller (roughly a major second wide) downward squeak – within the pitch range of the larger one. I noticed how the new diminuted gesture appeared spatially at a different position – towards the bottom of the wiper. And then the phone rang.

The content of an aural map is much more abstract than that of the geological or hydrological map. It is internal, individualistic, and inscrutable. But these properties also give it plasticity and allow us to reorganize it at every structural level, depending on prior experience and attentional regulation skills. While reading my recollection, you may have listened to and transformed the sounds in your mind's ear – possibly based on your Ea or musical listening skills and previous knowledge of a wiper squeak. You may have been able to perceive the relationships I described, though they were structured on imagined aural atoms. Similarly, the relationships I heard between the call and response – and separately between the calls and between the responses – were based on an imagined organization, an aural hypothesis that a continuous stimulus was comprised of two antiphonal parts. This hypothesis set the conditions for my perceptual organization throughout the listening experience, and provided filtered data.

It may be questioned whether data based on aural hypotheses are valid, because the hypotheses themselves may at times seem baseless. I propose that they are never baseless if one can organize his or her perception to hear them; their audibility is their basis. The plasticity of perception allows us to learn atomistic and synergistic hearing skills, but it also allows us to create and force our own atoms and structures. Therefore, we can investigate sonic stimuli by using existing analytical methods, but we could also listen 'outside the box' and collect evidence that emerge from setting up aural hypotheses, which may open up the way to new aural potentialities; both approaches are useful together.

Above all, creative aural hypotheses are justifiable because Ea music is an art form and because it evolves. We innovate by using new technologies, which lead to creating new sounds, which necessitate new ways of listening. In other times we listen in new ways, which leads to new sonic ambitions, which require new technologies. In both examples, aural innovation is central because aural perception is the interface with our consciousness – it determines our experience. The latter configuration, however, may be more oriented around the centrality of perception and therefore purposed more efficiently for aural innovation.

Conclusion

The atomistic/synergistic ear training/analysis approach is intended to provide perceptual breadth, precision, and flexibility. It is based on the principle that structures are hierarchically made from units and that they have different identities and properties from their components – a foundational principle of many existing analytical methods and systems across many sciences (Jayawardena, 2010). In this article I do not offer a detailed method of ear training or analysis, but principles for a perceptual approach that is designed to:

1. increase the structural range of aural perception (downwards towards smaller units, and upwards towards integration of multiple sets of information); and
2. increase the ease of navigation across them (by training aural focus on isolated parameters and training the ability to hear hypothesized atoms and synergetic structures).

This approach has been a guiding principle of my pedagogical decisions in teaching Ea aural training courses at Concordia for the past decade, and it has constantly provided new aural potentialities to investigate and new evidence from "places that weren't evidential before" – to quote Pople (2002: 20). Much of the new evidence was discovered, defined, and shared by students.

However, the biggest challenge in investigating perceptual experience is that it is inscrutable. Emerging evidence from aural investigation may be incorporated into an aural map in the consciousness of the perceiver, but we do not have the means (at least not yet) to correlate these qualitative experiences (qualia) with measurements (quanta) (Maudlin, 1989; Hurley and Noë, 2003; Dulany, 2014). To construct shared knowledge by integrating aural maps from multiple perceivers, future studies could involve a large sample of participants who would analyze shared aural stimuli through various filters (parametric foci and aural hypotheses). The participants would generate descriptions and graphic illustrations of their aural analyses, which could then be studied and compared by researchers. Until such study, however, we could gain understanding and aural skills by varying our analytical filters individually and exploring sonic stimuli from multiple perspectives.

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