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The spectral atom : cohesion of spectral particles in the music of Alvin Lucier.

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THE SPECTRAL ATOM
Cohesion of Spectral Particles in the Music of Alvin Lucier

By

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A Thesis Approved on

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DEDICATION

This thesis is dedicated to my father, Richmond C. Bausch (1952–2011).

There is so much I wish I could share with you and this thesis is only the tip of the iceberg. I would not be the individual that I am today without your love and guidance. Though I may not have the physical strength of Popeye, your memory has become my spinach for unleashing unbridled mental strength and perseverance.

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ABSTRACT

THE SPECTRAL ATOM

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Listeners often associate the music of Alvin Lucier with the practice of experimental music due to his unorthodox means of composition. By viewing his work in this way, whether consciously or subconsciously, his music is often treated as aleatoric. This classification ignores the compositional stimulus that fuels the creation of his music. Lucier's compositions are driven by the exploitation of one facet (or phenomenon) of sound. These sound phenomena take the form of spectral particles: vibrating media, acoustics, and psychoacoustics. The spectral particles uncovered in his pieces combine to form a spectral atom. By analyzing four of Alvin Lucier's works, *Twonings*, *Silver Streetcar for the Orchestra*, *I am Sitting in a Room*, and *Still and Moving Lines of Silence in Families of Hyperbolas*, I intend to extrapolate their spectral particles. A combination of these spectral particles will inform the spectral atom of the work in question.

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CHAPTER 1

INTRODUCTION

In 2014, I was introduced to *Never Having Written a Note for Percussion*, by James Tenney and *Silver Streetcar for the Orchestra*, by Alvin Lucier. I subsequently brushed both pieces to the wayside on account of their minimalistic and experimental nature. At the time, I was studying the music of Gérard Grisey and Tristan Murail, two composers who exploited timbre in a maximal way. I let my closed-mindedness get in the way of both Tenney's and Lucier's works and I now regret the time lost with their music.

A few weeks later, the final project for the class that introduced me to these pieces (Percussion Literature) consisted of a five-minute performance of *Silver Streetcar for the Orchestra*. Already having convinced myself that this piece required very little skill—to me, it was just hitting a triangle as fast as you could for five minutes—I approached the five minute performance without trying it in the comfort of a practice room. I thought to myself, how bad could it be? Needless to say, it did not go very well. I may have hit the triangle for five minutes, but I made no music. Much to my surprise, there was far more that went into this seemingly simple piece than I had thought. That same evening, I rushed into a practice room with my triangle and spent close to three hours lost in the overtones of this bent metal bar.

It was during this evening in the practice room that I realized how much skill and finesse went into performing music like this—I even programmed *Never Having Written a Note for Percussion* on my graduate percussion recital. More importantly, however, I learned that this music is just as "spectral" as the music of Grisey and Murail, but its spectral character occurs on a different level entirely: the microscopic. Though music cannot physically exist at a microscopic level—as music exists merely as a mental construct created by humans to honor collections and organizations of sound waves—in a metaphorical sense, I argue that intentions and processes *can* exist at this atomic level. In fact, I believe they *do* exist and I feel that Alvin Lucier's music is a particularly valuable key to understanding them as such.

Throughout this thesis, I intend to extrapolate the implicit characteristics of four works of Lucier's to further establish them as motives of spectral intent. These motives take the form of what I term *spectral particles* that exist to exploit a certain goal under the guise of acoustics, psychoacoustics, and vibrating media. Though each piece contains useful data in each of the three forms of spectral particles, often the piece in question will be heavily weighted toward only one or two of them. It is also not uncommon for each piece to contain multiple agents that work under the same spectral particle—for instance, under psychoacoustics, a single piece could feature the exploitation of the critical band as well as our perception of frequency discrimination.

The effects of these spectral particles combine to form what I term *spectral atoms*. In my conception, these spectral atoms exist through intent, *not* result. In other words, they do not come to fruition because of the way an instrument is interacting with a pure-wave oscillator, for example; they exist because the composer intended for them to interact that way. It is this fundamental difference in my theory of spectral atoms that elevates Lucier's music from the experimental to the intentional—and more specifically spectral. Composers like Grisey and Murail meticulously calculate which pitches and frequencies to use and when; their resultant timbres are premeditated and 100% intentional. Though Lucier's instructions often ask the performer to explore the range of performance possibilities during the performance—such as in *Silver Streetcar for the Orchestra*—the intended result is still consistent: the overtones of the triangle will still be projected.

Spectral atoms get their label from the overall spectral intention, whether that intention produces an entire work or a section of a piece. Therefore, the way in which the spectral particles coalesce is what gives each atom its character. It is important to note that the same spectral atom—such as atoms pertaining to attention or filtration, for example—can yield drastically different musical results. Despite these diverse results, what remains the same is the intention governing the music. As important as the spectral atom is in terms of the small-scale, these atoms are equally useful in analyzing the formal structures of large-scale works.

Alvin Lucier's Life

Born in 1931 in the town of Nashua, New Hampshire, Alvin Lucier remains active in the worldwide music scene—in fact, he had a recent performance on April 1, 2018 at Kyoto University in Japan. Alvin Lucier's childhood was rich with music. His father was a violinist but eventually pursued a career as a lawyer which culminated in his serving two terms as mayor in Nashua. His mother, an accompanying pianist, played piano for silent movies and played with her siblings in a dance band called the Lemery Trio. Reflecting on his childhood, Lucier recalls a memory of his mother:

> I also remember that before I ever knew anything about notes—maybe at the age of five or six—writing down a bunch of dots on a piece of music paper, and my mother would sit down and play beautiful melodies and arpeggios, pretending that that was what I had written.[1]

[1] Nicolas Collins, Ron Kuivila, and Andrea Miller-Keller, *Alvin Lucier: A Celebration* (Middletown, Conn.: Wesleyan University Press, 2011), 22.

Alvin Lucier endured an eclectic educational background. After his rejections to college post–high school, his mother enrolled him in a summer program at The Priori School in Rhode Island where he stayed for an additional year.[2] From the academic bolstering he received at The Priori School, he was accepted to Yale and received his Bachelor of Arts degree in 1954. He continued his graduate studies at Yale only to find that the compositional instruction was overly Eurocentric for his taste, and he decided to drop out after one year of study.

After several years working at a department store, he learned of the newly formed music department at Brandeis University, with Arthur Berger, Irving Fine, and Harold Shapero on faculty, and decided to apply. Prior to his studies at Brandeis, however, he attended Tanglewood in 1958 where he studied composition with Luka Foss and took orchestration classes from Aaron Copland. He would eventually earn a Master of Fine Arts degree from Brandeis University in 1960.

After his studies at Brandeis University he travelled to Rome for two years on a Fulbright Scholarship. It was in Rome where he immersed himself in the European *avant-garde* music of Nono, Boulez, and Stockhausen. Performances of

[2] It was at The Priori School where he witnessed a Trappist monk in the act of contemplation which provided the framework for his *Music for Solo Performer*. Collins, Kuivila, and Miller-Keller, 25.

music by John Cage and David Tudor, however, left a larger impression on him.[3] Prior to the newly discovered music of Cage and Tudor in Europe, Lucier practiced composing in a Neo-Stravinskian style but soon realized that it did not interest him. This cognitive dissonance resulted in a composing hiatus for several years after returning from Rome. He lived out this hiatus directing the Brandeis University Chamber Choir until 1970.[4]

In 1965, a turning point in Lucier's life and career, he invited John Cage to perform a concert at the Rose Art Museum. This concert featured the premier of Cage's *Rozart Mix* and Lucier's *Music for Solo Performer*. Then in 1966, together with Robert Ashley, David Behrman, and Gordon Mumma, Lucier formed the Sonic Art Union. The group "toured for a decade, presenting individual works, sharing equipment and assisting each other."[5]

Lucier's Music

Since *Music for Solo Performer*, Lucier has written over 100 works to date. These pieces range from solo to orchestral works and from sound installations to experimental music. With the eclecticism of his output, his music can be found all over the world and in any space available—in fact, some pieces, such as

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[3] Viola Rusche and Hauke Harder, "No Ideas but in Things: The Composer Alvin Lucier," accessed February 18, 2018, http://www.alvin-lucier-film.com/lucier.html.
[4] Viola Rusche and Hauke Harder, "No Ideas but in Things," (Mainz, Germany: Wergo, a division of Schott Music & Media, 2013).
[5] Collins, Kuivila, and Miller-Keller, 31.

Chambers (1968), *Vespers* (1968), and *Quasimodo the Great Lover* (1970), require finding unique and unconventional spaces to explore. Not only does he encourage an experimental attitude regarding space, but he also utilizes unconventional means to generate music—echolocation devices in *Vespers*, electroencephalography in *Music for Solo Performer*, and galvanic skin response sensors in *Clocker* (1978). Perhaps it is Lucier's eclectic attitude about what generates music and where it is performed that resulted in his being frequently labeled as an experimental composer. Though I will not argue that his tools are not experimental in nature, I will, however, argue that his music is much more than experimental.

Spectral Music

Some spectral composers utilized the increasing capabilities of computers in the 1970s as tools to revolutionize how music was written and understood. One new advancement in particular was the newly-developed ability to analyze sounds through the use of spectrograms and Fast Fourier Transforms. What these analyses revealed were the individual frequency components of a sound and their respective amplitudes. This birthed a new movement in the field of composition: spectralism. These composers used sound and its constituents as musical ideas to generate large-scale compositions.

Defining the term "spectral music" has proved difficult given that the composers within this school of writing find the term "spectral" inappropriate. For instance, Tristan Murail, in his article *Target Practice*, claims "they always call the music we make 'spectral'. Neither Gérard Grisey nor myself are responsible for that designation, which always struck us as insufficient."[6] It has come to be better understood that spectral music is more a compositional attitude rather than a form of writing replete with its own set of rules. In this same article, Murail states

> I do not believe, therefore, that one can speak of a 'spectral system' as such—[a system to assure the work's coherence such as the works by serially influenced composers]—if by that we understand a body of rules that will produce a product of a certain hue. I do believe, however, that one can speak of a 'spectral' attitude.[7]

Instead of it being a specific technique, what occupies the composers of this music is sound and its perception. Even the most common feature of spectral music—harmonic or inharmonic spectra—is considered a superficial construct.[8] Therefore, composers need a revised awareness of the musical phenomena. To understand and be able to write the music of this nature, Murail has provided a short, incomplete, list of precepts:

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[6] Tristan Murail, "Target Practice," *Contemporary Music Review* Vol. 24, no. 2/3 (Spring/June 2005): 149.
[7] Ibid., 152.
[8] Julian Anderson, "A Provisional History of Spectral Music," *Contemporary Music Review* Vol. 19, Part 2 (2000): 7–8.

1. thinking in terms of continuous, rather than discrete, categories (corollary: the understanding that everything is connected);
2. a global approach, rather than a sequential or 'cellular' one;
3. organizational processes of a logarithmic or exponential, rather than linear, type;
4. construction with a functional, not combinatorial, method; and
5. keeping in mind the relationship between concept and perception.[9]

Hermann Helmholtz, in 1850, discovered that the quality of sound was deeply influenced by its overtone content—both in terms of frequency and amplitude. What makes spectral music unique is how composers have abandoned traditional melodic cells and motives and instead respond to "complex physical circumstances like the overtone series."[10] In Grisey's *Transitoires* (1980–1981), for example, he analyzes the frequency content of a string bass to exploit what changes occur in the overtone structure as a result of five different ways of playing the instrument: pizzicato, normal, normal toward the bridge, almost on the bridge, and concluding with *sul ponticello*.[11] What is important about Grisey's techniques in *Transitoires* is not just the exploitation of the harmonic spectra, but the ability to do so with the new ability to literally see sound and its various characteristics.

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[9] Murail, "Target Practice," 152.
[10] François Rose, "Introduction to the Pitch Organization of French Spectral Music," *Perspectives of New Music* Vol. 34, no 2 (Summer, 1996): 7.
[11] Ibid., 11.

Lucier as Spectralist

As minimal or experimental as these pieces may be—often repetitive and exploratory in nature—the resulting music consistently adheres to the aesthetics produced by the spectral school of composers.[12] I believe his music has been paid little attention because of its unconventionality. To understand the application of spectral ideologies to the music of Alvin Lucier, I would first like to measure his music in terms of spectral characteristics. Simply accepting the notion that spectral music is more than just compositions that feature harmonic/inharmonic series widens the gamut to include his oeuvre for spectral consideration.

Much like the music of Grisey and Murail, Lucier has been interested in sound. His pieces center themselves around the exploitation of naturally occurring psychoacoustic phenomena. This has been his driving force for his compositions. In an interview with Douglas Simon he says:

> I didn't get inspired until I started investigating simple natural occurrences. Some composers find inspiration in words, in setting texts to music, or in politics, or drama, or in more abstract relationships, but I can't seem to get into those. … I seem to be a phenomenologist in some ways; I would rather discover new sound situations than invent new ways to put materials together. Whenever I think of changing direction, of making something more popular or attractive to a larger audience, I lose interest very quickly, so I follow my instincts and continue making pieces with brain waves,

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[12] Timothy Bausch, "Spectral Processes in the Music of Alvin Lucier," (lecture, The 9th Annual European Music Analysis Conference, University of Strasbourg, Strasbourg, France, July 1, 2017).

> echoes, room resonances, vibrating wires, and other natural phenomena, and try to put people into harmonious relationships with them.[13]

These thoughts reflect so clearly the goals sought by the canonic spectralists that this quote could easily have been said by any of them. The capability of computers to analyze sound became a tool for creative ways to put materials together. For Lucier, revealing subtleties within sound is a deeply personal experience and a large reason as to why he performs a lot of his own music. In an interview with William Duckworth he describes instances where the phenomena he is working with are so subtle that listeners may not feel they are listening to anything. He goes on to say "… the attention I put into the exploration [of the sound] is so intense that the listener does get something if he or she is willing to pay attention."[14]

Lucier's music aligns with spectral ideologies even further when compared to Murail's list of precepts. Of the four pieces discussed in this thesis—as well as a significant number of his other works—each work carries out a single idea as a continuation of a single process. Each work can be considered to have sectional divisions, but the musical process stays consistent throughout the entire body of work. This linearity addresses the first two precepts made by Murail.

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[13] Alvin Lucier, Gisela Gronemeyer, and Reinhard Oehlschlägel, *Reflections: Interviews, Scores, Writings*, (Cologne: MusikTexte, 1995), 194.
[14] Ibid., 40.

Throughout these works, the generative material is the process. These processes feature a duality of concept and perception with the former exploiting the latter. The scale of Lucier's music clashes with Murail's belief that linear organizational processes do not belong in spectral music. Because Lucier's music features a single phenomenon that is exploited over an extended period of time, his segmentation of the music does not call for organizational processes. Instead, the sections—if any—are developmentally static when compared to previous sections or feature an altered version of the same kind of phenomenon-supporting music.[15]

In Joshua Fineberg's article, *Guide to the Basic Concepts and Techniques of Spectral Music*, he defines spectralism "as a special case of the general phenomenon of sound." He continues by adding that the composers "consider music to ultimately *be* sound."[16] Unlike the canonic spectral composers, such as Gérard Grisey and Tristan Murail, Lucier's music exists on a much smaller scale while still maintaining spectral integrity. In the same vein as these other spectral composers, Lucier focuses on sound as the main idea of his music.

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15 Lucier's music is considered developmentally static when compared to examples of Murail's works that feature exponential or logarithmic development of harmonic, timbral, and rhythmic material across singular works such as *Gondwana*.

16 Joshua Fineberg, "Spectral Music," *Contemporary Music Review* Vol. 19, part 2 (2000): 2–3.

Let us return to my brief description of Grisey's *Transitoires*. Since computers allow composers to take a visual snapshot of a sound, the composer can analyze the sound's individual characteristics such as overtone structure and frequency amplitudes. Much like what Grisey did for *Transitoires*, composers can use this data to generate compositional material. What I find unique about Lucier's music is that, instead of analyzing a snapshot of a sound on a computer to expose its overtone intricacies, he asks a musician to perform a repeated musical task for an extended period of time. This repetition gives the audience a chance to hear the overtone complexities instead of presenting the analyzed data as a piece—such as what Grisey had done. Although it is not visual, the repetition that is prolonging the sound is acting like an acoustic spectrogram for the audience. Consider Lucier's *Piper* (2000) for solo bagpipe; the performer sustains the same sound for a long period of time while walking around the performance space. Though no analytical data is accumulated from a performance of *Piper* like Grisey would discover for *Transitoires*, Lucier manages to transform the solitary act of analysis into a public performance. This transference of roles—from pre-composition to performance—is prominent in many of his works including *Silver Streetcar for the Orchestra* and *I am Sitting in a Room* which will be discussed further in this thesis.

It is this act of performing the exploration of sound that most qualifies Lucier as a part of the spectral school. What Grisey and Murail achieve in their music differs minimally—mostly only in amount of ideas used—to Lucier's. I believe that Lucier's pieces function as singular entities—as they often only feature one phenomenon at a time—that combine to form canonic spectral works. Moreover, I believe that his works, more specifically his intentions, function as spectral atoms. They take the form of spectral atoms because of the singular intention that governs each of his pieces. These intentions are related exactly to the intentions found in the canonic spectral works. It is the combination of these spectral atoms that form spectral works of a larger scale.

The Spectral Atom

I am arguing that the sonic world of Alvin Lucier can be explained using spectral ideologies. To address his music through this lens, I introduce the new concept and terminology of spectral atoms. This thesis, in a metaphorical sense, looks at Alvin Lucier's music on a microscopic level. Since pieces of music cannot literally be addressed in a microscopic way, I am adopting a metaphorical parallelism to the atom found in the study of physics. The atom, in the field of physics, is considered to be the building block of ordinary matter. Analogously, the spectral atom, in my analytical framework, is the building block of all spectral music.

To discover a spectral atom within a piece of music, I “magnify” the music—much as a scientist would reveal atoms with a powerful microscope. This magnification goes well beyond that of phrases or gestures to, instead, focus on three different components of sound, which I call spectral particles, and how the listener perceives them: acoustics, psychoacoustics, and vibrating media. In each of the pieces discussed in this thesis, I will identify the spectral particles that are used and combine them into their own unique spectral atoms.

Continuing with the physics metaphor, spectral particles are analogous to subatomic particles (constituent smaller particles that make up the physical atom). Spectral particles occur in three different forms: acoustic, psychoacoustic, and as vibrating media and, like the subatomic particles, combine to form spectral atoms. Though all pieces with sound consist of these three crucial elements, Lucier exploits them as either individual entities or through combinations of multiple particles.

Let us first define what qualifies each spectral particle: acoustic spectral particles relate strictly to the vibrational habits of spaces and their related medium. This includes the resonating frequencies of various spaces such as concert halls or classrooms as well as how the propagating medium affects the sound waves in their respective space. The discussion on the vibrating media particle—the ultimate source of the piece’s sound—will feature the unique physical characteristics of the various objects that produce sound in his works. After the sound has been made, the space has a large effect on what the sound does. The analysis of various standing waves within a space can be calculated to understand what these spaces do to the sound. In addition to the space's filtering characteristics, analyzing the unique patterns in reverberation will provide insight as to what happens to the sound on the way to the listeners' ear. Once the sound traverses its way through the space, the psychoacoustic particles will activate once the sound enters the ears. The various psychoacoustic phenomena discussed include beating, perceived time, masking, filtering, and vertical/horizontal scene organization.

The significance of the spectral atom is its ability to represent the intentions of multiple spectral particles into one concise idea or intention. Identifying the spectral atom (or atoms) that govern Lucier's works not only provides insight into his decisions governing his compositions but can be expanded to inform formal analysis of other spectral works. Spectral pieces do not often conform to standard forms such as binary or ternary. Instead, many focus on acoustical processes in a modular form—similar to Karlheinz Stockhausen's concept of moment form.[17] The spectral atom allows the analyst to

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[17] Moment form refers to sections of a piece of music that form an "experimental unit" as opposed to motivic and phrase development. "Moment form," *Grove Music Online,* February 14, 2018,

attach a name to these modular musical units, both on the small scale found in pieces by Alvin Lucier, but also on a larger scale in pieces by established spectral composers such as Gérard Grisey or Tristan Murail.

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http://www.oxfordmusiconline.com/grovemusic/view/10.1093/gmo/9781561592630.001.0001/omo-9781561592630-e-0000018920.

CHAPTER 2

APPROACHING SPECTRAL MUSIC

Introduction

When analyzing music at the particle level, it is important to identify and understand the various concepts and their associated terminology. Throughout this chapter, I will investigate what constitutes each spectral particle. Beginning with vibrating media and continuing through acoustics to psychoacoustics, definitions of the concepts associated with each particle will be presented. Understanding of these concepts is paramount to the comprehension of what organizes the spectral atoms in Lucier's music.

More importantly, however, is the connection of these concepts to the institution of spectralism. With the ultimate goal of classifying Lucier's music as spectral, it is vital to understand the mechanics of spectral music. Much like how the understanding of harmony is useful for analyzing classical music, comprehending the fundamentals of sound and its perception is critical for grasping the intentions of spectral composers. Therefore, the intent of this chapter is to provide the fundamental concepts for vibrating media, acoustics, and psychoacoustics through the lens of their compositional applications.

Vibrating Media

Perhaps the most fundamental concept to understand, as it is the basis for all of Lucier's music, as well as every analyzed phenomenon in this thesis, is sound. At its most basic definition, what we consider a sound is vibrating particles (usually air) that propagate away from a sound-source. Without a medium to vibrate—whether it be air, water, wood, etc.—sound cannot exist. The pattern in which these particles propagate consists of a series of points that fluctuate through condensation and rarefaction—where the particles become closer together and further apart in relation to their points at rest.[18] This type of wave is called a longitudinal wave and is prone to reflections off of various surfaces, though it weakens as it travels along its trajectory.[19] Figure 2.1 provides a visual representation of a longitudinal wave.

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[18] As a sound travels from its point of origin outwards, the particles maintain their average location in the space and do not move with the traveling sound.

[19] Brian C. J. Moore, *An Introduction to the Psychology of Hearing*, 6th ed. (Leiden: Brill, 2013), 2.

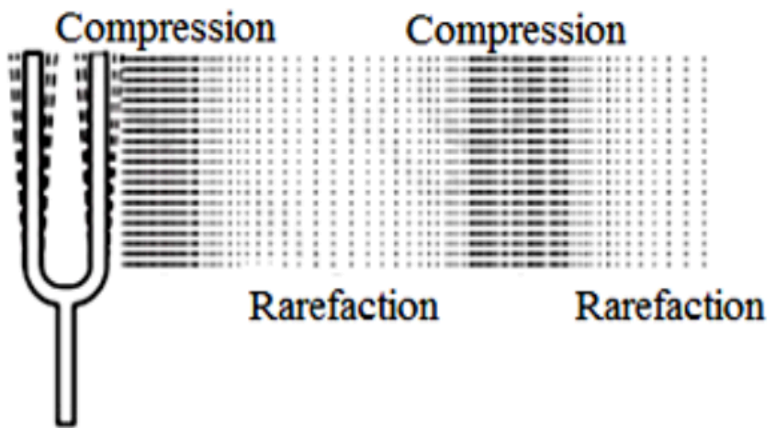

Figure 2.1: Visualization of the compression and rarefaction patterns in air.[20]

Unlike the longitudinal wave, transverse waves are created from lateral displacements in the vibrating media that utilize longitudinal waves to propagate. One of the easiest types of transverse waves to study—and Lucier's favorite—is the sine-wave; Lucier frequently refers to these as pure-waves on account of how our ears perceive their tone quality. All sine tones require three variables: amplitude, phase, and frequency.

The amplitude of a sound wave is associated with the loudness of the wave or "the amount of pressure variation about the mean."[21] To illustrate what wave amplitude is, refer to Figure 2.2. Simply put, the amplitude is measured by how far the wave crosses the horizontal line (mean) on both sides. Let us assign the maximum amplitude of the first peak as 1. Assuming the first trough—

[20] Gurmeet Kaur, "Cbse Class 9 Science, Sound: Chapter Notes (Part-I),"
https://www.jagranjosh.com/articles/cbse-class-9-science-sound-chapter-notes-1510911147-1.
[21] Moore, 2.

occurring at phase 270—contains the same amplitude energy, it can be labeled as -1.

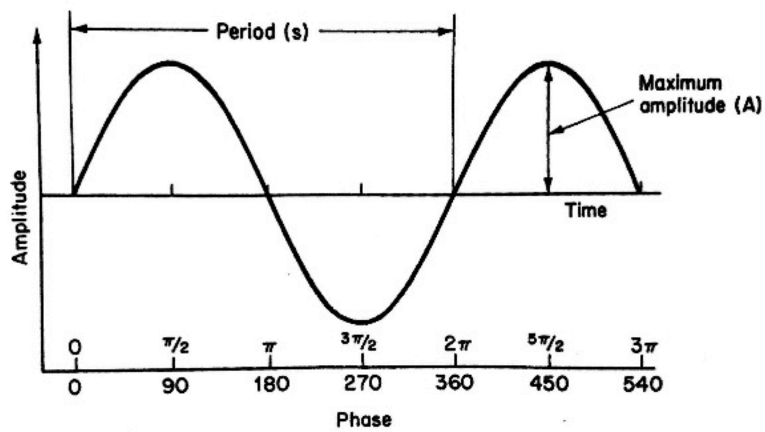

Figure 2.2: A visual representation of a sine wave. The graph shows its three variables: amplitude shown on the y-axis, phase on the x-axis, and the period is highlighted on the sine wave itself.[22]

The phase of the wave is determined by what the amplitude of the wave is at any given time—often in relation to another wave.[23] When recalling Figure 2.2, the phase is labeled on the x-axis in degrees where if, for example, this wave started at 180º, the wave would be 180º out of phase compared to the original.[24] Waves of the same frequency and amplitude that are 180º out of phase with each other will cancel out. This is because, when sound waves are presented concurrently, their amplitudes will sum together. If a simple sine wave features a maximum amplitude of 1, a like-wave that is 180º out of phase will have an

[22] Ibid., 3.
[23] The peak of the wave is synonymous with the compressions of the longitudinal wave and likewise the valley of the wave is synonymous with rarefactions.
[24] Moore, 2–4.

amplitude of -1; when added together, this results in an amplitude of 0. On the other hand, if these two waves were in phase with each other, their summation will result in a max-amplitude of 2 (and -2) essentially reinforcing the sound to double its original amplitude.

Frequency, what listeners typically refer to as pitch, is defined as how many times per-second the wave completes a full cycle—also referred to as period as labeled in Figure 2.2. This is referred to as Hertz (Hz) where 1 Hz classifies a wave that completes one full cycle per-second. It is important to note that the period, or frequency, is not strictly attached to the sine tone. All periodic waves, no matter their complexity, contain a period.

Frequency provides a very useful springboard to discuss the construction of the overtone series.[25] François Rose describes the overtone series as "a theoretical concept which describes a set of vibrations whose frequencies are all integral multiples of one fundamental frequency."[26] What this means is that an overtone series is generated from one frequency called the fundamental frequency. This is the lowest frequency in a sound. Each subsequent frequency in the overtone series is calculated by multiplying the fundamental by the partial

[25] Throughout this thesis, partial and harmonic are used interchangeably. The first partial or harmonic is considered as the fundamental. The first overtone, however, references the second partial or harmonic of the harmonic series.
[26] François Rose, "Introduction to the Pitch Organization of French Spectral Music," *Perspectives of New Music,* Vol. 34, no. 2 (Summer, 1996), 7.

number. Figure 2.3, taken from Rose's *Introduction to the Pitch Organization of French Spectral Music*, displays a harmonic series of 32 pitches generated from an E_1 of 41.2 Hz. Labeled above each pitch is the partial number.[27]

Figure 2.3: Harmonic series of the fundamental E1. The series is represented in musical notation.

The harmonic series proves useful only for explaining harmonic sounds. Oftentimes, the sounds in question do not conform to whole-number multiples of a fundamental frequency. In this case, the sound is considered to be inharmonic. These sounds are far more common than one might think. For instance, we will visit vital roles played by inharmonic instruments such as the triangle, glockenspiel, and even the piano. When presented with an inharmonic sound, the best way to analyze its frequency components is through a Fast Fourier Transform (FFT) analysis. This kind of analysis relies on the theory that

[27] The pitches were rounded to the nearest 1/4 or 1/6 tone labeled above the pitches in question for clarification. Ibid., 7.

any complex sound can be recreated by combining individual sine tones and their unique amplitude and phase information. Therefore, by breaking down complex sounds into their individual sinusoids any sound can be represented by its component parts.[28]

Of the instrument families discussed throughout chapter 3—strings, woodwinds, voice, keyboard, and percussion—the string family most consistently follows the harmonic series. What is less consistent about string instruments, however, is their uniformity of frequency response throughout their playable range.[29] Figure 2.4 shows a comparison of the frequency response curves of a violin versus a cello. How can these differ so greatly if both instruments operate by simple vibrating strings? This is because the unique construction of each string instrument results in different vibrational modes. In describing the tone production of string instruments, Neville H. Fletcher and Thomas D. Rossing claim that

> the most important determinant of the sound quality and playability of a string instrument is the vibrational behavior of its body. … The normal modes of vibration or eigenmodes of a violin are determined mainly by the coupled motions of the top plate, back plate, and enclosed air. Smaller contributions are made by the ribs, neck, fingerboard, etc.[30]

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[28] I use FFT analyses to project the overtone construction of the triangle in *Silver Streetcar for the Orchestra* into musical notation.

[29] In this case, frequency response refers to the difference in amplitude of certain resonant frequencies.

[30] Neville H. Fletcher and Thomas D. Rossing, *The Physics of Musical Instruments* (New York: Springer-Verlag, 1993), 247.

These vibrational patterns are affected by anything from differing dimensions to wood thickness and curvature. Therefore, the individual pitches performed by string instruments will be harmonic in structure, but some will resonate stronger or weaker depending on the instrument's vibrational mode.

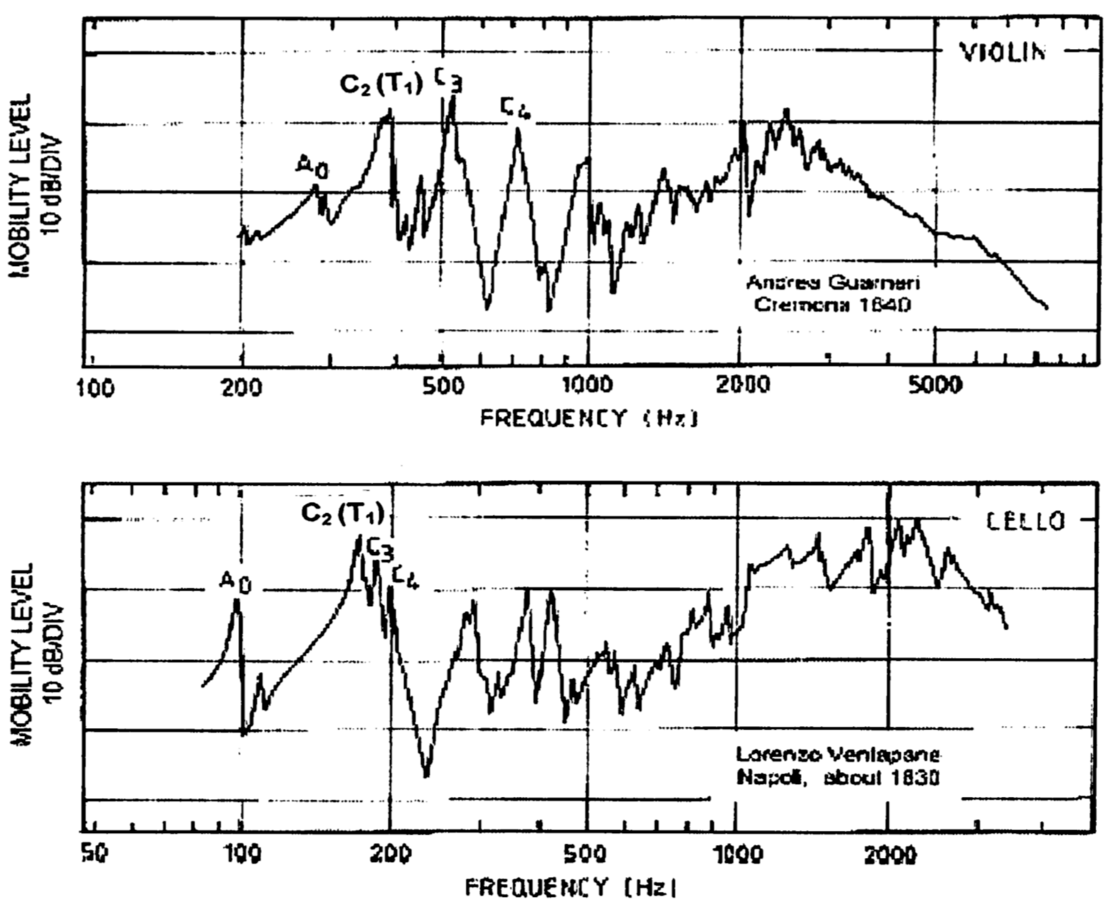

Figure 2.4: Frequency response curves of the violin (top) and cello (bottom).[31]

The piano, another instrument involving strings, is more complex. The main sound-amplifying component of the piano is the soundboard and it

[31] Eric Bynum and Thomas D. Rossing, *The Science of String Instruments* (New York, NY: Springer Science and Business Media, LLC, 2010), 248.

operates quite similarly to string instruments. What is interesting, however, is the inharmonic nature of the piano. As will be discussed in further detail in the next chapter, the outer registers of the piano are tuned so that the octaves are larger than a 2:1 ratio. Figure 2.5 shows a graph of tuning averages by a professional tuner (referred to as a fine tuner) and measurements taken from O. L. Railsback. A point of importance for this thesis is how this inharmonic nature interacts with the cello in Lucier's *Twonings* (see pages 53–56).

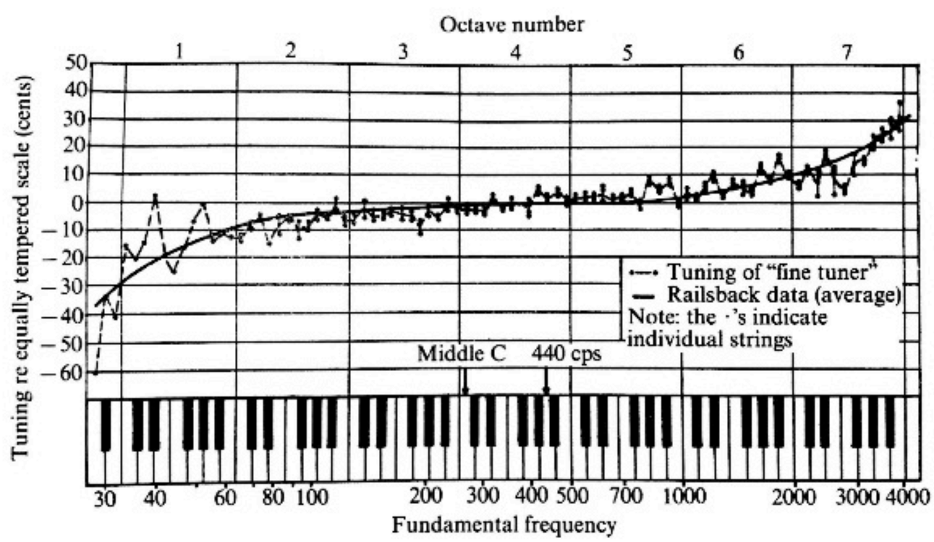

Figure 2.5: Average tuning across the range of the piano.[32]

Percussion instruments provide many useful sound sources for Lucier. For example, the inharmonic nature of the percussive triangle gives *Silver Streetcar for the Orchestra* a myriad of sonic possibilities to explore. Another inharmonic percussive instrument is the glockenspiel—featured in *Still and*

[32] Fletcher and Rossing, 335.

Moving Lines of Silence in Families of Hyperbolas. Because the fundamental frequencies of the glockenspiel bars are so high, the sound decays quickly and, therefore, "little effort is made to bring the inharmonic overtones of a glockenspiel into a harmonic relationship through overtone tuning."[33]

The overtone structure of the marimba bars follows an unconventional tuning system. What makes the marimba's tuning so unique is that marimba tuners only focus on the first seven partials, yet these do not conform to the typical harmonic series. In fact, many of the overtones in the harmonic series are simply not present in marimba bars. The second partial of a marimba bar, for example, would coincide more with the fourth partial in the natural harmonic series. This results in the absence of both the octave and twelfth (partials 2 and 3 in the harmonic series) from the overtone structure of the marimba bar. The partials that are present, though more harmonic than the glockenspiel, are tuned slightly inharmonic. Some of the overtones even decay prior to the fundamental reaching its maximum amplitude. For instance, with a fundamental of 169 Hz, the second partial of the marimba—again, compared to the fourth partial of the typical harmonic series—is tuned 3.9 times higher at 663 Hz. The following

[33] Ibid., 534.

partials are tuned to 9.2, 16.2, 24.2, 33.5, and 42.9 times the fundamental, respectively.[34]

Much like the glockenspiel, the xylophone's upper harmonics are not generally considered—the one exception being the first audible overtone sounding a musical 12th above the fundamental. This is because the resonators below each bar—closed pipes tuned to the fundamentals—reinforce the frequency three-times that of the fundamental. The musical 12th, or the third partial, focused on by tuners of the xylophone will be reinforced by the resonators giving it "a much crisper, brighter sound than the marimba."[35]

The vibraphone bars also feature an inharmonic spectrum. The inharmonicity changes depending on where the pitch is in the range of the vibraphone. Figure 2.6 shows the tuning modes of three different pitches on the vibraphone. What is unique to the vibraphone, however, is the lengthy decay time caused by the aluminum bars in conjunction with closed resonators that essentially reinforce the already vibrating bar through sympathetic vibration.[36]

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34 The tuning of the higher partials becomes less important as the fundamentals rise on the marimba. Ibid., 536–39.

35 Ibid., 544–45.

36 Ibid., 546–47.

n	f_n	f_n/f_1	f_n	f_n/f_1	f_n	f_n/f_1
1	175	1	394	1	784	1
2	700	4.0	1578	4.0	2994	3.8
3	1708	9.7	3480	8.9	5995	7.6
4	3192	18.3	5972	15.2	9400	12.0
5	4105	23.5	8007	20.2	14,014	17.9
6	6173	35.4	11,119	35	18,796	24.0
7	8080	46.3			21,302	27.2

Figure 2.6: Tuning modes of three different notes on the vibraphone.[37]

Psychoacoustics

Perhaps the most important spectral particle for the purposes of this thesis, psychoacoustics deal with how sounds are physically heard and mentally perceived by listeners. As sounds propagates through the air, they are funneled into the auditory canal where the sounds meet the eardrum. Once the sound meets the eardrum, the air vibrates the eardrum. The auditory ossicles, the malleus, incus, and stapes—more commonly known as the hammer, anvil, and stirrup, respectively—are responsible for transmitting the eardrum vibrations to the oval window, the opening to the cochlea. The cochlea, arguably the most important structure responsible for perceiving sounds, is the frequency analyst of the auditory system. Within the cochlea lies the basilar membrane which is responsible for detecting frequency information of incoming sounds. The organ

[37] fn represents the fundamental frequency of the bar and fn/f1 represents the ratio to the fundamental. The first column shows the tuning modes for pitch F_3, the middle column shows the tuning modes for pitch G_4, and the rightmost column, G_5. The vertical lines were added to increase comprehension. Ibid., 547.

of Corti is located on the basilar membrane and is responsible for sending nerve impulses from the basilar membrane to the brain. Within the organ of Corti are hair cells which are in close proximity to the tectorial membrane. As the basilar membrane vibrates, the stereocilia protruding from the hair cells are bent against the tectorial membrane triggering the parent hair cells to send the impulses to the brain via the cochlear nerve. The basilar membrane vibrates in a mirrored fashion to the incoming audio waveform whereas the vibrating points on the basilar membrane correlate to the frequencies present in the incoming signal.[38]

Leading articles give definitions of the different concepts associated with different phenomena that the cochlea struggles to decode. Daniel Pressnitzer and Stephen McAdams discuss a myriad of terms relating to perception in their article "Acoustics, Psychoacoustics and Spectral Music." They begin with the discussion of sum and difference tones and how humans hear phantom tones within a sound even if they are not present in the original source. This is caused by the basilar membrane combining and subtracting the frequency data from the incoming signal resulting in combination and difference tones. These phantom tones culminate in the summation of the two frequencies and the difference of the two frequencies.[39]

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[38] Moore, 23–35.

[39] Daniel Pressnitzer and Stephen McAdams, "Acoustics, Psychoacoustics and Spectral Music," *Contemporary Music Review* Vol. 19, Part 2 (2000), 44.

The basilar membrane is also responsible for producing beats when two frequencies are too close within the critical bandwidth. The critical bandwidth is a phenomenon that affects our perception of frequencies that are too close together. When an added frequency to an already present sound falls within this critical bandwidth—a frequency range relating to a certain center frequency—it is perceived as one pitch with added beating. Furthermore, within this critical bandwidth the perception of two distinct tones is impossible. Figure 2.7 shows the curve of the critical bandwidth on a frequency scale. The curve in Figure 2.7 can be used to identify the center frequency of this bandwidth by dividing the y-axis frequency by 2. The resulting frequency determines how wide the bandwidth is at a particular frequency range (x-axis). For example, at 700 Hz, our critical bandwidth, according to Figure 2.7, is 100 Hz. Therefore, any frequency that is ± 50 Hz (100 Hz divided by 2) of 700 Hz will fall within the critical bandwidth. Moreover, an added tone that falls within the critical bandwidth will be perceived only to affect the already present tone. This will cause the present tone to beat instead of being perceived as two separate tones. The rate at which the beating will occur is equal to the absolute value of their frequency difference—a difference of 10 Hz will cause a beating rate of 10 beats per second.[40]

[40] Ibid., 44–47.

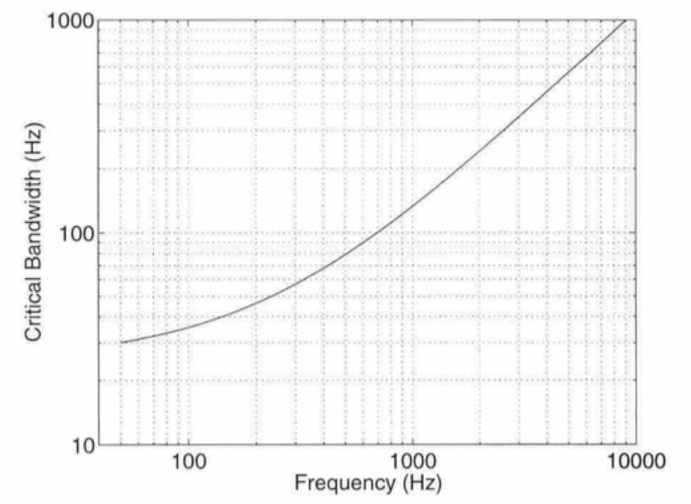

Figure 2.7: Frequency curve of the critical bandwidth. Center frequency listed on the x-axis and critical bandwidth on the y-axis.[41]

The concept of adaptation has strong relevance throughout this thesis. Moore defines adaptation as increased neural activity in response to a new signal and notes that neural activity decreases with the persistence of the same signal. Given the repetitive nature of Lucier's works, adaptation plays a large role in phasing out parts of the sound to allow the listener to focus on other sonic events.[42]

Since having performed *Silver Streetcar for the Orchestra* many times, I am consistently fascinated with how much time passes during a performance. This fascination has driven me to investigate this anomaly further: does the presence of reverberation contribute to our deflation in perceived time. A frequent comment after a performance of *Silver Streetcar for the Orchestra* is that the listener

[41] ibid., 45.
[42] Moore, 50–51.

had no idea how much time had passed. The frequency of this comment encouraged me to pursue the idea of time perception within this piece further. In doing so, I have completed the initial stages of a qualitative study in which I have probed 34 students on various questions on comparing two identical recordings of *Silver Streetcar for the Orchestra*; one with reverberation, one without. The results—given in detail in the next chapter—supported continuing this investigation by developing a quantitative experiment.

The hypothesis is grounded in the fact that, due to its amplification, the triangle's presence is magnified in the space in which it is being performed and the reverberation levels must therefore increase. The presence of the reverberation does several things: it softens the abrasive attacks of the triangle, it allows for overtones to sustain through reinforcement, and it increases the complexity of the sound by combining new sound events with lingering events. Figure 2.8 is taken from Kristina Knowles's dissertation, "The Boundaries of Meter and the Subjective Experience of Time in Post-Tonal Unmetered Music, to show the relationship between complexity and perceived time.[43]

[43] Kristina Knowles, "The Boundaries of Meter and the Subjective Experience of Time in Post-Tonal, Unmetered Music" (PhD diss., Northwestern University, 2016), 176.

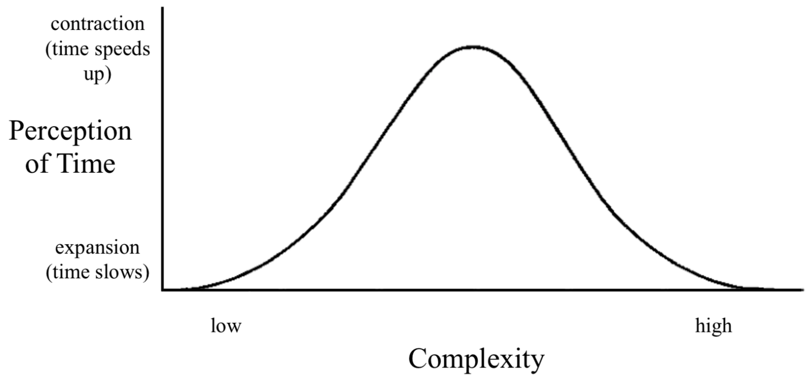

Figure 2.8: Representational curve of perception of time in relation to complexity.[44]

The last perceptual topic that is relevant to this thesis is the human ability to discriminate between changing frequencies and tempi. Frequency discrimination is tested two different ways, both of which involve asking subjects to compare two successive tones. One of the two ways to test this phenomenon is by comparing simple changes in frequency between successive pitches. The results of this first method are measured in difference limen for frequency (DLF). The second method also utilizes two successive tones; however, instead of changing frequency, one of the tones is frequency modulated. The results of the second method are measured in frequency modulation detection limen (FMDL). This concept is applied to Lucier's *Still and Moving Lines of Silence in Families of Hyperbolas* and, since the instruments operate more on the former experimental design, I chose to ignore the findings for FMDL.

[44] Ibid., 176.

Much like frequency discrimination, tempo discrimination has also been tested through a multitude of approaches. Many experiments testing tempo discrimination involve the comparison of two tempos. A limitation is that, as Kim Thomas says, "these studies all speak more to memory for duration than discrimination thresholds of just noticeable difference in tempo change."[45] To combat these issues, both Thomas and Mark C. Ellis created experiments in which tempos decreased or increased *while* the participants were listening. Thomas relied on simple sine tones to present the sequence of tempo shifts—"sine waves were used rather than complex waves to prevent the ear from having to perform an additional analysis."[46] Ellis, on the other hand, used a simple melody consisting of 24 quarter notes. While the participants were listening, he would increase the tempo in increments of 2% using the staircase method: if a 2% change resulted in a "no change" response, an additional 2% change would occur until the subjected responded that a change had occurred. At this point the process was reversed by a 2% change in the opposite direction until a change was recorded.[47]

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[45] Kim Thomas, "Just Noticeable Difference and Tempo Change," *Journal of Scientific Psychology* (May 2007): 17, https://pdfs.semanticscholar.org/8a8f/80588a0e40cba56018e53827a14e9af0d3a7.pdf.
[46] Ibid., 17.
[47] Mark C. Ellis, "Research Note. Thresholds for Detecting Tempo Change," *Psychology of Music* Vol. 19 (1991): 165–66.

Acoustics

It could be argued that particles associated with vibrating media—the physics behind the sound sources—are subsets of acoustics. Though this is a perfectly true statement, I approach the "acoustic" spectral particles in this thesis in two ways. First, I am interested in what causes the sound waves to change before a listener can process the sound (psychoacoustics) and if an external stimulus acted upon the sound source (vibrating media). To understand these manipulative forces, I place my focus on the space in which the music exists and whether any important anomalies occur within the space. The second approach to acoustics as a spectral particle deals with the organizational schemes attached to collections of sounds. More specifically, I am interested in the tuning systems designed to organize musical pitches. It is important to note that this is *not* the same as the tuning of the overtones of a sound—that, to me, is still part of sound generation.

Of the many tuning systems that exist, I focus my attention on equal temperament and just intonation. Equal temperament was designed to create twelve equal divisions of the octave and is also known as twelve-tone equal temperament. Mathematically, it is quite simple to represent as a formula with s representing interval:

$$1, s, s^2, s^3, s^4, s^5, s^6, s^7, s^8, s^9, s^{10}, s^{11}, s^{12}$$

Knowing that the octave, $s^{\wedge}12$, must equal 2, the formula can calculate the size of the interval $s = \sqrt[12]{2}$. This results in a value of approximately 1.05946 meaning that the frequency of each consecutive step in the scale is a multiple of 1.05946 of the preceding step.[48]

Unlike equal temperament, the system of just intonation is less commonly attached to creating musical scales and instead focuses more on the tuning of intervals. This is not to say that a just scale does not exist. In fact, Harvey E. White and Donald H. White discuss in their book, *Physics and Music: The Science of Musical Sound*, the calculation of a just diatonic scale.[49] Though the logistics of just diatonic scales are beyond the scope of this thesis, it is important to note that the just tuning of intervals produces similar ratios to the sample just diatonic scale discussed by White and White. To compare just intonation and equal temperament, I discuss the just intonation system as if the justly tuned intervals have been normalized into the same octave—much like the just diatonic scale—to mimic the discussion of equal temperament.

One of the main differences between equal temperament and just intonation is that just intonation includes pure intervals such as just thirds and

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[48] William A. Sethares, *Tuning, Timbre, Spectrum, Scale*, 2nd ed. (London: Springer, 2005), 56–57.
[49] Harvey E. White and Donald H. White, *Physics and Music: The Science of Musical Sound* (Philadelphia: Saunders College Pub., 1980), 173–74.

sixths as well as pure fifths and fourths.[50] The ratios of these just intervals are found in the harmonic series mentioned above—hence their pure quality. For example, the fifth scale degree (an intervallic fifth above the tonic), with a ratio of 3:2, can be found between partial 3 and partial 2 of the harmonic series.[51] The reflection of the harmonic series in the interval ratios extends throughout the just intonation system. One of the drawbacks to this system is that it is key specific, meaning the tunings were generated from a given fundamental. Therefore, the intervallic ratios are not the same in all keys.[52]

The concept of standing waves (room modes) has been an important area of focus for acousticians, architects, and recording studios for many years. Recalling the discussion on phase, waves that are considered to be "in phase" interfere constructively—meaning the waves will increase in amplitude—consequently, waves that are considered to be "out of phase" interfere destructively meaning the amplitudes will diminish. With an understanding of how phase affects amplitude, we can begin to understand how Lucier utilizes room modes as a tool.

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[50] Though, it can be argued that every interval in the just intonation system is considered "pure" due to its calculations based on the harmonic series. It is more common to focus on the fifths, fourths, and both major and minor thirds. This is because the ratios all consist of small numbers: 1–6. Ibid., 173–74.

[51] This differs from the Pythagorean tuning system in which the ratios are devised from the consecutive tuning of pure fifths.

[52] Ibid., 60–64.

The first, and easiest to understand, room mode is the axial room mode. The axial room modes occur between two opposing surfaces—the floor and ceiling or opposing walls, for example (see Figure 2.9 below).[53] The axial mode reveals the wavelength that fits in the individual dimensions of the room. To calculate the axial modes of a given room follow the formula,

$$f_{x(axial)} = \frac{c}{2}\left(\frac{x}{L}\right)$$

where *c* is the speed of sound, *x* is the mode number, and *L* is the length of the room. It is important to note, however, that both *W* (width) and *H* (height) can be substituted for *L* to calculate the room modes of the other dimensions of the room.[54]

The next kind of room mode is the tangential room mode. This mode occurs between four surfaces (see Figure 2.9 below) and reveals the wave length that fits between these surfaces. In other words, tangential modes consist of a single wavelength that reflects off the four surfaces before reaching its point of origin. This type of mode is found between adjacent dimensions such as *L+W*, *W+H*, and *L+H.* By modifying the axial mode formula to include the second room dimension, the tangential room modes can be calculated:

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[53] In this setting, the term mode is synonymous to overtone when thinking of the harmonic series. For instance, mode 1 is considered the fundamental and each subsequent mode is an integer multiple of mode 1.

[54] David M. Howard and Jamie Angus, *Acoustics and Psychoacoustics*, 5th ed. (New York; London: Routledge, 2016), 331.

$$f_{xy(tangential)} = \frac{c}{2}\sqrt{\left(\frac{x}{L}\right)^2 + \left(\frac{y}{W}\right)^2}$$

where the addition of y represents the mode number of the second surface.[55]

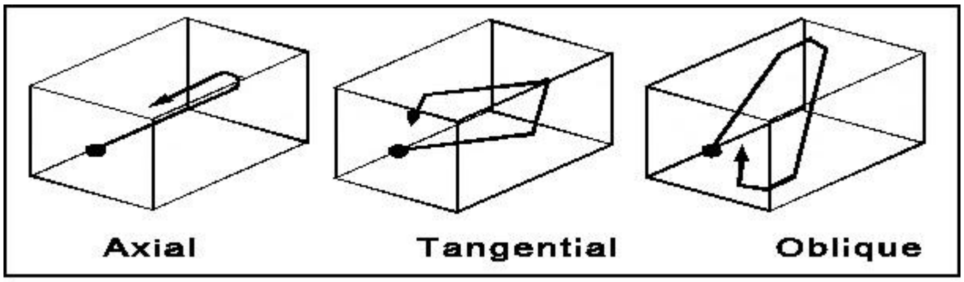

Figure 2.9: Visual representation of the three types of room modes.[56]

The last type of room mode is called the oblique room mode featuring a wave that reflects off all six sides of the room. These modes are the longest of the three room modes but feature the highest mode 1; this means that the fundamental of the oblique mode is higher in frequency than both the axial and tangential modes. To include the added dimension of the oblique modes, another addition to the room mode formula is needed:

$$f_{xyz} = \frac{c}{2}\sqrt{\left(\frac{x}{L}\right)^2 + \left(\frac{y}{W}\right)^2 + \left(\frac{z}{H}\right)^2}$$

With this formula, being able to account for all three dimensions of the room, we can realize both axial and tangential room modes as well. By putting a 0 in the

[55] Like the axial mode formula, *L*, *W*, and *H* can be substituted, in which case the variable in the numerator is the mode number for the surface represented in the denominator. Ibid., 332.
[56] Shelly Williams, "What Are Room Modes," GIK Acoustics, April 1, 2009, accessed March 17, 2018, http://www.gikacoustics.com/what-are-room-modes/.

numerator of any of the fractions under the radical, the fraction cancels itself out allowing calculations for specific dimensions if needed.[57]

Another way to extrapolate the same data is to perform an impulse response of a room. During an impulse response, either a sine wave sweeps across the range of human hearing (typically 20–20,000 Hz) or a burst of white noise filling the same frequency spectrum is projected into the room. Concurrently with the projection, a recording is made of the responses of the room. Analyzed for peaks in amplitude, these frequencies are then extrapolated to reveal the frequency imprint of the room. Figure 2.10 shows a frequency spectrogram of an impulse response of my office, room 224 in the University of Louisville's School of Music.

[57] Ibid., 33–35.

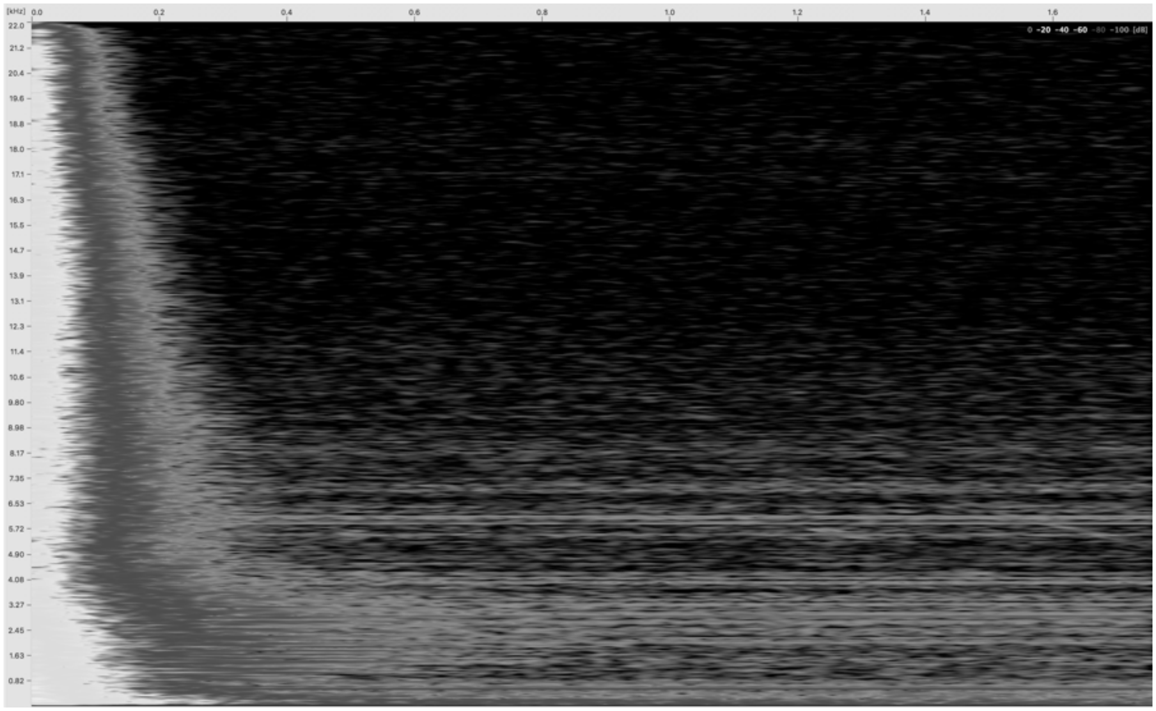

Figure 2.10: Spectrogram of impulse response. The impulse response was conducted in room 224 of the University of Louisville's School of Music. The amplitude scale displays louder frequencies in white.[58]

Another important acoustic concept is reverberation. As mentioned previously, waves—whether longitudinal or transverse—reflect off objects. Objects with different materials contain different absorption coefficients—the lower the coefficient, the less sound is absorbed and this results in reflections. After a sound is presented into a space, eventually—close to instantaneously—"there is a dense set of reflections arriving at the listener. This … is called reverberation and is desirable as it adds richness to and supports musical sounds."[59] Figure 2.11 shows a side-by-side comparison of the same recorded

[58] The impulse response was done using the Impulse Response Utility included in Apple's Logic Pro X software.
[59] Ibid., 294–95.

finger snap except that the spectogram on the left has no reverberation and the one on the right has added reverberation. It is clear to see how many frequencies reinforce themselves with the presence of the reverberation.

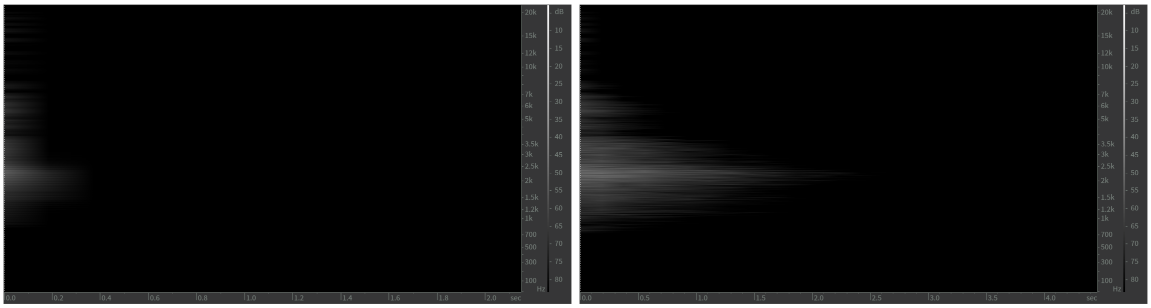

Figure 2.11: A spectrogram comparison of a dry finger snap (left) and the same recorded finger snap with added reverberation (right).

Applications and Conclusions

What makes each of these concepts so vital to the spectral school is that they provide a generative seed for spectral composers. With the common thread amongst spectral composers being the exploitation of the characteristics of sound, it is no coincidence that these seeds have every bit to do with sound. The comprehension of these fundamental concepts is merely a starting point to fully understand their application in a compositional setting.

Considering, for example, Grisey's *Partiels*, we can trace the compositional choices made in the first two sections of this piece by understanding the underlying phenomena. The first section of music focuses on the transition from a harmonic spectrum of musical pitch E_1 to an inharmonic spectrum. Without the knowledge of the harmonic series, it would be difficult to justify the harmony as well as its trajectory. Grisey continues into the next section where he utilizes the beating that occurs between a dyad as a tool to realize subsequent rhythmic constructions. At rehearsal mark 15, two clarinets are sustaining a dyad of 134.7 and 146.8 Hz. In this case, the difference between the two frequencies equals 12.1 Hz, or pulses per second. The wooden drum, introduced just after this dyad, appears at a rhythm of seventeen in the space of two, or in this given tempo, 12.5 attacks per second. In comparison to the 12.1 Hz difference tone, it is a near exact match, especially considering the representation in musical notation.

Theorist Robert Wannamaker has conducted analyses in a similar manner. In his article "North American Spectralism: The Music of James Tenney," he lists attributes that are most commonly associated with spectral music:

- A general preoccupation with the phenomenology rather than the semantics of sound.
- The use of the harmonic series as an intervallic resource.
- The orchestration of spectra in which instruments are assigned to individual spectral components such as partials; this includes so-called 'additive instrumental synthesis' in which such orchestration is guided by the spectrographic analysis of acoustical sources, and orchestration of electroacoustic source materials by analogous means.
- An interest in the perceptual duality of timbre and harmony by way of which a given collection of tones might, depending on its specific constitution and the attitude of the listener, either perceptually fuse into a unitary percept with a characteristic *steady-state timbre* or alternatively might dissociate into multiple perceptually autonomous tones possessing a *harmonic* relationship.
- The musical application of various acoustical or psychoacoustical concepts including harmonic fusion, residue pitch, difference tones, Shepard-tone phenomena, and amplitude or frequency modulation, etc.

- The invocation of gradual formal processes that allow (and encourage) attention to subtle phenomenal details.[60]

Wannamaker claims that James Tenney utilizes all of these characteristics "in parallel [with] and some of which anticipate European [spectral] developments."[61] He briefly credits Alvin Lucier as a part of the North American spectral movement—though he does not give any examples.

What the following chapter will accomplish is similar to what Robert Wannamaker does in his article. I intend to apply the topics defined in Chapter 2 to Alvin Lucier's music to uncover the intentions and processes exploited in his music. In each piece, I will focus on the acoustic, psychoacoustic, and vibrating media, enabling us to identify the main spectral atom in the piece.

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60 Robert A. Wannamaker, "The Spectral Music of James Tenney," *Contemporary Music Review* Vol. 27, part 1 (2008), 91–92.
61 Ibid., 92.

CHAPTER 3

ANALYSES

Twonings

General

Written for Charles Curtis and Joe Kubera in 2006, *Twonings,* for cello and piano, features unison long tones to exploit the dichotomy of just intonation and equal temperament. The score is written in a rather unique way: both instruments share one staff in the score—as they both play the same written pitch—each note sounding one octave higher than written—with the cellist only playing in natural harmonics on the string corresponding to the written Roman numeral below the notated pitch. Composed entirely in whole notes, the score requires the performers to sustain each note until the sound decays—longer still for the sectional fermatas.

Twonings owes its success to the concurrence of just intonation and equal temperament in the cello and piano, respectively. The exploitation of these two tuning systems can be broken down into multiple spectral particles that will aid in our understanding of the processes that Lucier uses in this composition. Because the cellist is playing solely natural harmonics, each pitch produced follows the natural harmonic series of the particular string that is being excited. The piano, however, only roughly follows the equal tempered tuning system, though more on the intricacies of the stretched harmonic tuning of the piano will be given later (see pages 53–56). The resulting sounds produced through the intricacies of each instrument's tuning characteristics cause audible beating between the instruments due to the closeness of the respective frequencies. This beating occurs because the human cochlea cannot process two adjacent frequencies if they fall within the critical bandwidth.

Acoustics

Without the presence of two different tuning systems, *Twonings* would represent nothing more than an exercise in long tones. As mentioned previously, the cello conforms naturally to the system of just intonation. This system of tuning relies on small interval ratios to produce pure intervals such as the fifth, major/minor third, and major/minor sixth.[62] The ratios required to produce the pure intervals in question correlate to the overtones of the harmonic series. Figure 3.1 shows the harmonic series to the 16th partial.[63]

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[62] Sethares, 60–61.
[63] Notation has been rounded to the nearest half-tone for ease of readability.

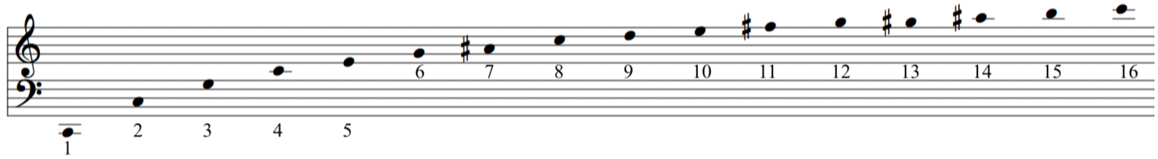

Figure 3.1: The harmonic series of C_2 to the sixteenth partial rounded to the nearest half-tone.

Distances between certain pitches of this harmonic series form the ratios necessary to justly tune the intervals in relation to the fundamental—for ease of comparison to equal temperament, the ratios are organized in a chromatic scale. Referring to Figure 3.2, the numbers in the ratios correlate to the partial number in the harmonic series. For example, the ratio 9/8, found for the major second, can be found between partials 9 and 8 of the harmonic series. Notice how the fifth (G) and the thirds and sixths (D-sharp, E, G-sharp, A) are coupled with simplistic ratios; this was the intent of the tuning system.[64] Due to the performance instructions, the cellist is incapable of performing notes that fall outside of the harmonic series. Because of this tuning system's strict allegiance to the harmonic series, the performance technique of the cello places its pitch firmly in just intonation.

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[64] Note also that these ratios are found very low in the harmonic series; all occur below the 8th partial.

Just Intonation		
	Ratio	Cents
C	1/1	0
C#	16/15	112
D	9/8	204
D#	6/5	316
E	5/4	386
F	4/3	498
F#	45/32	590
G	3/2	702
G#	8/5	814
A	5/3	884
A#	16/9	996
B	15/8	1088
C	2/1	1200

Figure 3.2: Ratio and cent calculations of a just intonation scale based on pitch-class C.[65]

The piano, on the other hand, cannot conventionally play harmonics, nor is the performer asked to do so in this piece. After many decades of development, the piano has been firmly stuck into the system of equal temperament. This system contains zero pure intervals at the expense of creating equal divisions of the octave. On the other hand, just intonation, while offering pure intervals, is key-specific: to play a piece in C major with the tuning of C-just intonation will sound consonant because the tuning system is modeled after pure intervals from the tonic. In contrast, playing a piece in F-sharp major in the same tuning of C-just intonation would not yield the same purely tuned results because the intervals were not measured from the F-sharp tonic.

[65] Modified table. Sethares, 62.

If we revisit Figure 3.2, showing just intonation, the ratios are simplistic, though the cents are less than predictable. If we compare just intonation with equal temperament, such as Figure 3.3, we notice a lack of rational number ratios—the ratios were rounded to decimals for ease of readability. There is, however, a consistent and predictable series of an increase in 100 cents per semitone in the cents column in the equal tempered system. A comparison of these two systems, converting ratios into decimals, shows the subtle differences between the two tunings. As subtle as these differences in ratio appear, when applied to frequency, they produce large differences, some even close to 70 Hz.

Just Intonation			Equal Temperament			Difference	
	Ratio	Cents		Ratio	Cents	Ratio	Cents
C	0	0	C	0	0	0	0
C#	1.066	112	C#	1.0595	100	0.0065	12
D	1.125	204	D	1.1225	200	0.0025	4
D#	1.2	316	D#	1.189	300	0.011	16
E	1.25	386	E	1.260	400	0.01	14
F	1.333	498	F	1.335	500	0.002	2
F#	1.4062	590	F#	1.4142	600	0.008	10
G	1.5	702	G	1.498	700	0.002	2
G#	1.6	814	G#	1.5874	800	0.0126	14
A	1.666	884	A	1.682	900	0.016	16
A#	1.777	996	A#	1.7818	1000	0.0048	4
B	1.875	1088	B	1.888	1100	0.013	12
C	2	1200	C	2	1200	0	0

Figure 3.3: Comparison of a just intonation based on pitch-class C and equal temperament.[66]

[66] Modified table. Ibid., 57–62.

Though *Twonings* does not relate to a specific scale, the harmonic series of each cello string governs the structure of each section of the piece.[67] Figure 3.4 displays the partials used in each section of *Twonings*. Figure 3.4 clearly shows a process as each section, delineated by a break in the line, follows a specific pattern. Not only does it show a pattern, it proves that just intonation is the driving force of this piece. Each section follows a pattern in that a clear predictable choice of partials can be observed. The easiest example is looking at the partials from 233 (on the x-axis) to the end: the partials rise from 6–12 and repeat.[68]

[67] Each section concludes with a fermata in the score.
[68] What is not shown in Figure 3.4 is the choice of string. The pattern from 233 to the end features a rise in partials from 6–12, the four repetitions of this rising pattern go through each of the cello strings as well.

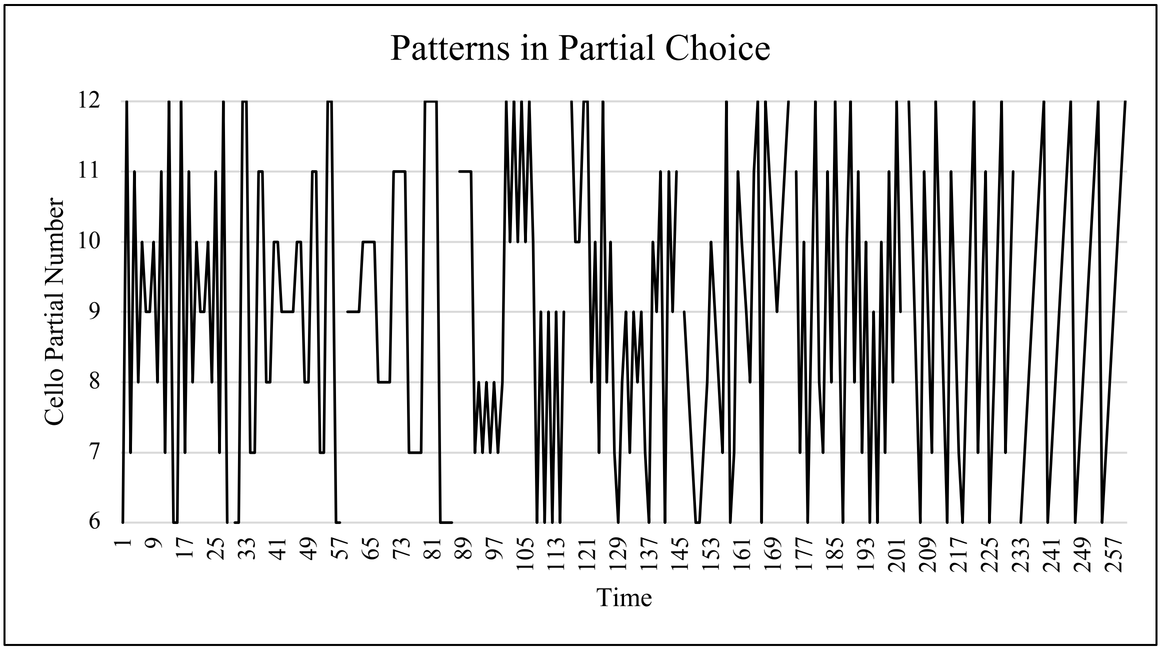

Figure 3.4: Graph displaying the partial number—not string specific—throughout the course of *Twonings*. The string partial is represented on the x-axis and successive pitch on the y-axis.

Psychoacoustics

The piece's title is a pun that alludes to the main intent of the piece: tuning. As mentioned previously, the dichotomy of just intonation and equal temperament will cause minute pitch discrepancies that result in a phenomenon known as beating. Beating is perceived as amplitude pulsations in the sound. The rate of the beating pulsations that is heard can be calculated precisely. To arrive at this important piece of information, the frequency information for each pitch is required for both instruments.

Obtaining the frequency information for the pitches played by the cellist is a simple matter of a mathematical equation:

$$f_x = (f \times x)$$

where variable f represents the fundamental frequency in Hz, x represents the partial number, and f_x represents the frequency of partial x in Hz. To apply this formula, the fundamental frequency information of the four strings of the cello is needed. Referencing the table of frequencies found in Joshua Fineberg's "Guide to the Basic Concepts and Techniques of Spectral Music," the four fundamental frequencies in question are 220, 146.83, 98, and 65.41 Hz for strings I–IV, respectively. Figure 3.5 displays the resultant frequencies (in Hz) when the fundamentals have been applied to the harmonic series formula.

		String			
		I	**II**	**III**	**IV**
P	6	1320	880.98	588	392.46
a	7	1540	1027.81	686	457.87
r	8	1860	1174.64	784	523.28
t	9	1980	1321.47	882	588.69
i	10	2200	1468.3	980	654.1
a	11	2420	1615.13	1078	719.51
l	12	2640	1761.96	1176	784.92

Figure 3.5: Frequencies of partials 6–12 of each cello string in Hz.[69]

The next step is to determine which partial each pitch corresponds to in the score. To do this, using the software tool OpenMusic, I generated a harmonic series on each of the cello strings in the form of pitch notation. The generated material in Figure 3.6 simplifies the process in deciphering the partial of each pitch. For example, the first pitch in the score—a sounding A_5—is to be played on

[69] Figure 3.5 only calculates partials 6–12 because Lucier only uses these partials in *Twonings*.

string II. Looking through the harmonic series of string II in Figure 3.6, it is clear that A_5 is partial 6 of string II. Because the frequencies are being calculated per string, if the same pitch is found on multiple strings two different frequencies will result depending on the fundamental of the string. For example, partial 8 of string II and partial 12 of string III are both D_6 but the frequencies calculate out to be 1174.64 and 1176, respectively.

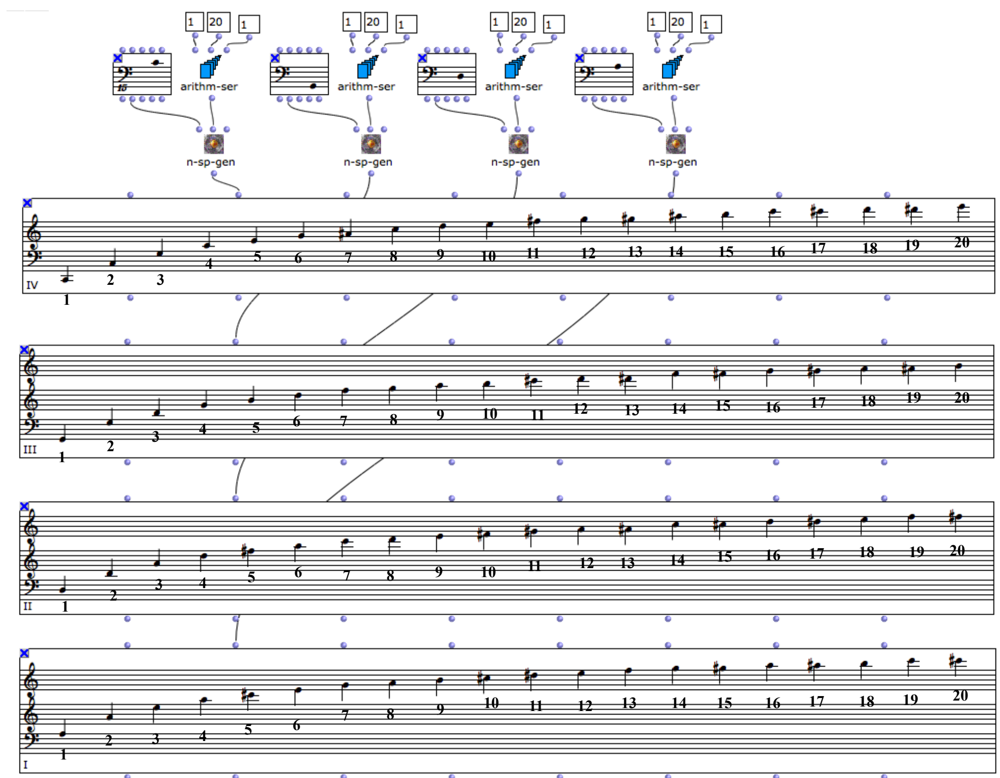

Figure 3.6: Harmonic series of each cello string rounded to the nearest semitone.

Unlike the cello, the piano is far more complicated in terms of realizing frequencies. This is due to its equal tempered tuning coupled with its intentional stretching across octaves. Due to the inconsistencies of tuning, the data included in this thesis will be based on the information provided in Alfred H. Howe's

Scientific Piano Tuning and Servicing.[70]

Figure 3.7 shows the calculations for the first section of the piece. The column of interest is the "Frequency Difference" column. This number is the absolute value of the difference between the cello and piano frequencies. This number is how many times per-second an audible pulse occurs in our ears. For instance, the fourth dyad that is heard in *Twonings* will result in a perception of 30.48 pulses per second. This is due to our ear's incapability of perceiving more than one frequency if the frequencies present are too close. This phenomenon, as mentioned previously, is known as the critical bandwidth and only exists in our perception of the sound, not in the physical world.

[70] Alfred H. Howe, *Scientific Piano Tuning and Servicing*, (Tuckahoo, N.Y.1963), 30.

Time (pitch)	String	Partial	Cello Frequency	Piano Frequency	Frequency Difference
1	2	6	880.96	880	0.96
2	3	12	1176	1174.4	1.6
3	2	7	1027.81	1046.4	18.59
4	3	11	1078	1108.48	30.48
5	2	8	1174.64	1174.4	0.24
6	3	10	980	987.68	7.68
7	2	9	1321.47	1318.4	3.07
8	3	9	882	880	2
9	2	10	1468.3	1479.68	11.38
10	3	8	784	783.84	0.16
11	2	11	1615.13	1661.12	45.99
12	3	7	686	698.4	12.4
13	2	12	1761.96	1760	1.96
14	3	6	588	587.2	0.8
15	1	6	1320	1318.4	1.6
16	4	12	784.92	783.84	1.08
17	1	7	1540	1567.68	27.68
18	4	11	719.51	739.84	20.33
19	1	8	1760	1760	0
20	4	10	654.1	659.2	5.1
21	1	9	1980	1975.36	4.64
22	4	9	588.69	587.2	1.49
23	1	10	2200	2216	16
24	4	8	523.28	523.2	0.08
25	1	11	2420	2488.96	68.96
26	4	7	457.87	466.16	8.29
27	1	12	2640	2636.8	3.2
28	4	6	392.46	391.92	0.54

Figure 3.7: String, partial, frequency, and frequency difference data for the first section of *Twonings*.

When looking at a spectrogram image of this same dyad (Figure 3.8), it is visibly clear that the psychoacoustic presence of the beating does not match how the sound waves are behaving in the physical environment outside of human ears. In Figure 3.8, the two horizontal frequencies—1078 Hz (bottom horizontal white line) and 1108.48 Hz (top horizontal white line)—propagate through the time domain as two steady frequencies void of any amplitude fluctuations.[71]

Figure 3.8: Spectrogram image of frequencies 1108.48 Hz (top horizontal white line) and 1078 Hz (bottom horizontal white line) to show steadiness in amplitude despite aural beating.

Lucier's decision to utilize partials 6–12 of the cello further supports how important the critical bandwidth is to this piece. As mentioned previously, the largest frequency differences occur on partial 11 on strings I and II. Partial 11 on string I consists of 2420 Hz and 2489.96 Hz on the cello and piano, respectively. To calculate the center frequency, the average of the two instrument's frequencies is needed: 2454.98 Hz. When compared to Figure 3.9, this center

[71] The spectrogram displays time on the x axis and frequency on the y axis. The level of amplitude for each individual frequency follows the scale displayed to the right of the figure—the louder the frequency, the whiter it appears.

frequency has a bandwidth of roughly ± 190 Hz (labeled 1 on Figure 3.9). Partial 11 on String II, 1615.13 Hz and 1661.12 Hz on the cello and piano, respectively, has a center frequency of 1638.13 Hz and a critical bandwidth of roughly ± 95 Hz (2 on Figure 3.9). Therefore, since the largest frequency gaps fall within the critical bandwidth, it is safe to assume the rest of the smaller gaps will fall within the critical bandwidth as well.[72]

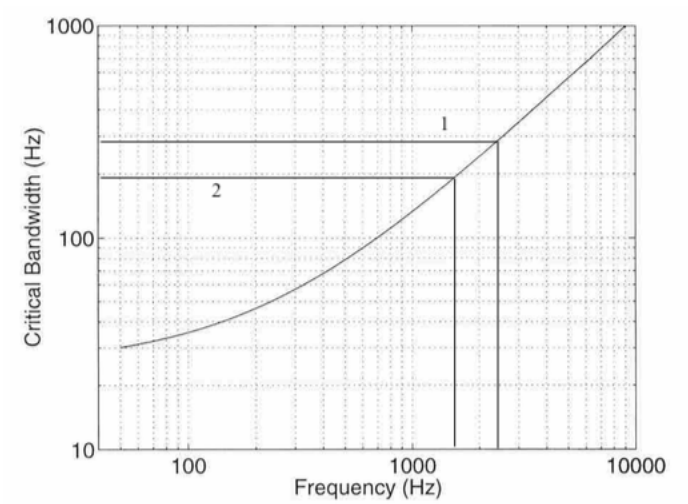

Figure 3.9: Frequency curve of the critical bandwidth with lines added for center frequencies 2454.98 Hz (1) and 1638.13 Hz (2) to aid in visualization.

Vibrating Media

As touched upon earlier, the success of this work owes itself to the way in which the cello and piano produce sound. The instrument that creates the interference in *Twonings* is the piano due to the intentional inharmonicity of its

[72] The smallest critical bandwidth of this piece, based upon the lowest frequencies, has a center frequency of 392.19 Hz and a corresponding critical bandwidth of roughly ± 34 Hz.

tuning.[73] This occurs because of the physical characteristics of the high-strength steel wire. To reduce the level of inharmonicity present, piano wires feature tensions upwards of 1000 N/mm^2 (30–60% yield strength of the wire) and the smallest diameter wire as possible.[74] However, there is also a psychoacoustic element to our preference for stretched tuning. Fletcher and Rossing continue to discuss that humans perceive sequential or simultaneous octaves as being perfectly in tune when their interval is about 10 cents (0.6%) greater than the typical 2:1 frequency ratio.[75] Figure 3.10 shows a graph created by Schuck and Young displaying inharmonicity curves of five different piano strings; note the rapid increase of the curve as the notes increase.

[73] A sound is considered inharmonic if the overtones aren't whole-integer multiples of the fundamental frequency.
[74] Fletcher and Rossing, 316.
[75] Ibid., 335.

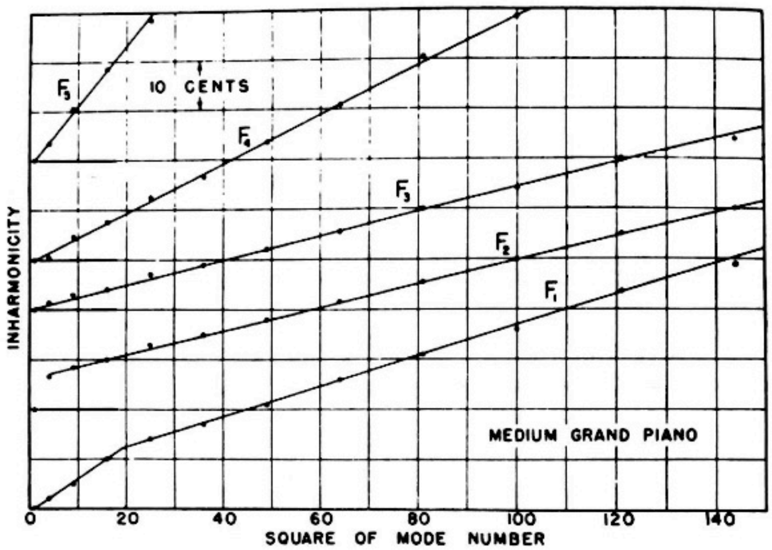

Figure 3.10: Graph taken from Fletcher's *Physics of Musical Instruments* to demonstrate the increasing inharmonicity as pitch rises on piano. Originally appears in research conducted by Schuck and Young.[76]

Considering the range of the piano utilized in Twonings the amount of beating that occurs becomes clear. Ranging from G_4 to E_7, the music falls within the area of the piano that has the largest amount of inharmonicity. Assuming that the highest pitches played by the piano will create the largest tuning differences is unsafe as it only accounts for one element. This assumption would imply that each cello pitch conforms to equal temperament—already previously found to be untrue.

When organizing the frequency data of *Twonings* by partial number, it is clear that partials 11, and 7 of the cello feature the greatest frequency difference against the piano. To illustrate the reasoning for this, I will focus on normalizing

[76] Ibid., 336; O. H. Schuck and R. W. Young, "Observations on the Vibrations of Piano Strins," *The Journal of the Acoustical Society of America* Vol. 15, no. 1 (1943): 5.

the overtones of string IV of the cello into the same octave to make a scale for comparison purposes. The 11th, 7th, and 10th partials of string IV are pitch classes F-sharp, B-flat, and E, respectively. Referencing back to Figure 3.3, a comparison can be made between the ratios of just intonation and equal temperament for these partials: Pitch class F-sharp has a ratio difference of .008, B-flat has a difference of .0048, and E has a difference of .01.

Though these partials differ significantly when compared to equal temperament, what is even more striking is the frequency difference as the strings increase in pitch. As the strings get higher, the pitch consequently also rises on piano. As the pitch gets higher on piano, the more inharmonic the piano becomes. When analyzing the relationship that partial 11 across the four strings has with the piano, a noticeable trend occurs in frequency difference. Starting with the lowest string for partial 11 there is a frequency difference of 20.33 Hz. As we follow this partial across the four strings we see the frequency difference rise to 30.48 Hz on string III, 45.99 Hz on string II, and an astonishing 68.96 Hz on string I.[77]

[77] Accompanying piano pitches: F-sharp$_5$, C-sharp$_6$, G-sharp$_6$, and D-sharp$_7$, respectively.

Conclusion

In summation, the acoustic spectral particle deals with the two tuning systems between the cello and piano. Concurrently, the vibrating media particle explains the overtone structure of the cello as well as the inharmonicity of the piano. The presence of both the acoustic and vibrating media particles results in the psychoacoustic particle. This particle consists of the beating that is caused because of our critical bandwidth's inability to segregate closely tuned frequencies. These three particles combine to form the spectral atom of tuning. The tuning spectral atom reflects the intention of Lucier to exploit both the dichotomy of just intonation versus equal temperament as well as the inharmonicity of the piano.

Silver Streetcar for the Orchestra

General

Written for amplified solo triangle, *Silver Streetcar for the Orchestra* (1988) explores the resonance of the common percussive instrument. Lucier asks the performer to repeatedly strike the triangle at an initial tempo marking of "eighth note equaling metronome marking 320" for no more than 20 minutes while muting the triangle between the thumb and forefinger.[78] Throughout this performance, the performer manipulates five performance parameters: muting location, muting pressure, striking location, striking strength, and tempo. Manipulating only one parameter at a time, the performer alters each parameter gradually and imperceptibly.[79] This process of slow change allows the triangle to emit variations of its unique harmonic structure. The effectiveness of *Silver Streetcar for the Orchestra* lies in the intertwining of its spectral particles. The increased level of reverberation caused by amplification allows for the overtones of the triangle to be heard more clearly, subsequently creating an increase in arousal (interest) for the listener; without the presence of reverb, the piece would not be as effective.

Vibrating Media

Given its non-pitched nature, the triangle emits an inharmonic spectrum meaning that overtones do not conform to whole-number multiples of its fundamental. Neville Fletcher and Thomas Rossing describe the triangle:

> Because of their many modes of vibration, triangles are characterized as having an indefinite pitch. They are normally steel rods bent into a triangle (usually, but not always, equilateral) with one open corner. Triangles are suspended by a cord from one of the closed corners, and are struck with a steel rod or hard beater.

[78] Alvin Lucier, "*Silver Streetcar for the Orchestra*," (Frankfurt am Main: Alvin Lucier, distributed by Material Press, 1988).
[79] Ibid.

> Triangles are typically available in 15-cm, 20-cm, and 25-cm (6-, 8-, and 10-in.) sizes, although other sizes are also used. Sometimes one end of the rod is bent into a hook, or the ends may be turned down to smaller diameters than the rest of the triangle to alter the modes of vibration. The sound of the triangle depends on the strike point as well as the harness of the beater.[80]

The triangle used in my performance, and subsequent study for this thesis, was a 6-inch model by Black Swamp Percussion.

The last sentence of Fletcher and Rossing's description regarding the strike point location on the triangle is of particular importance for the work. Figure 3.11 shows a performance of *Silver Streetcar for the Orchestra* and illustrates that frequencies disappear and reappear as time progresses in the piece. This is caused by the constant shifting of parameters by the performer. What this spectrogram also supports is the inharmonic nature of the triangle—discussed as indefinite pitch by Fletching and Rossing—with several extraneous frequencies in the low range as well as multiple clusters of frequencies throughout the upper range.

[80] Fletcher and Rossing, 551.

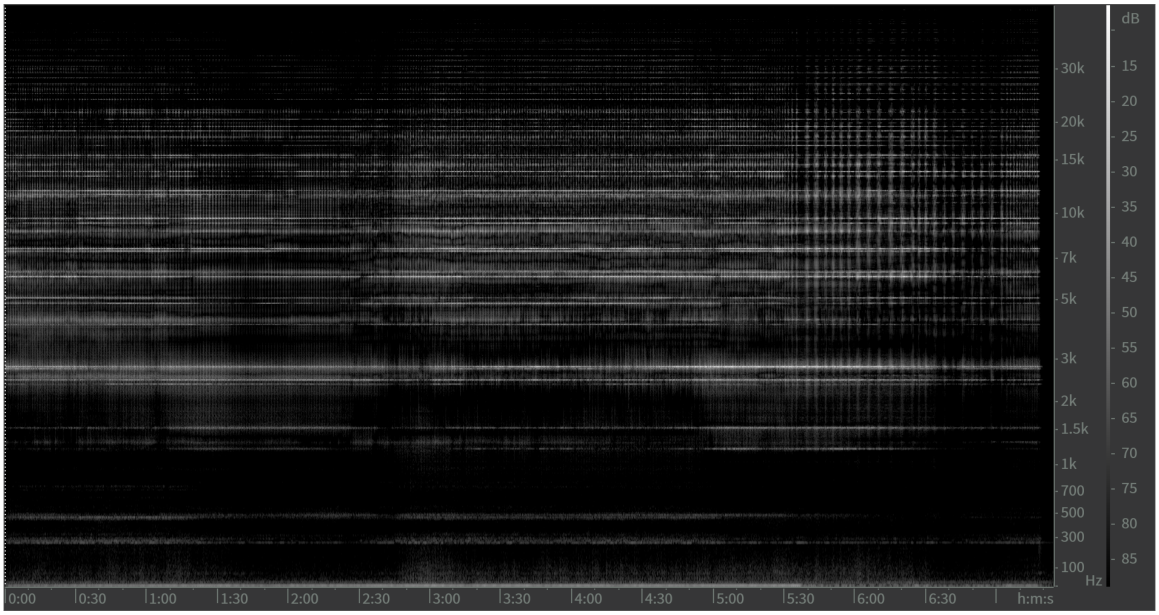

Figure 3.11: Spectrogram view of an entire performance I recorded of *Silver Streetcar for the Orchestra*.

In addition to the unique spectra of the percussive triangle, there are a myriad of different performance techniques that excite the triangle in different ways. The steel rod, or beater, that Fletcher and Rossing describe striking the triangle comes in various diameters. Each beater excites the triangle in a different way to produce a distinct overtone sonority. To demonstrate this, I recorded a single strike of the triangle maintaining attack velocity and beating location on the triangle throughout the recordings. Using the sound data from four different beaters—yellow (1/8”), red (3/16”), green (7/32”), and black (9/32”)—I input the analyses into Openmusic to generate each spectrum as a notated chord.[81]

[81] The set of graduated beaters, organized by color, were designed by Grover Percussion and each beater’s diameter is expressed in inches in parentheses. Each note of the chord was rounded to the nearest 16th tone.

Looking at Figure 3.12, it is clear to see that as the beater diameter increases, the more overtones are present in the sound.

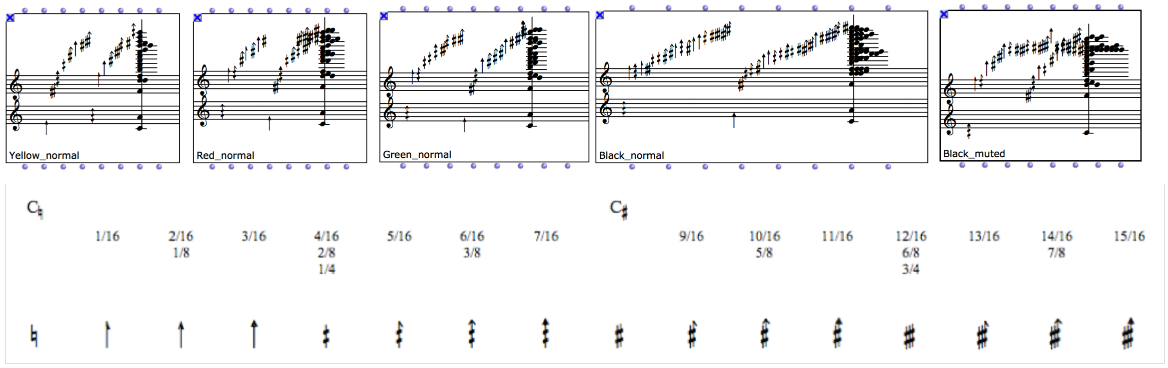

Figure 3.12: Five spectra, represented in musical notation, of various triangle beater sizes. The range of accidentals is included below the chords to illustrate the various microtonal notation.[82]

Fletcher and Rossing classify the triangle as being a non-pitched instrument and Figure 3.12 completely supports this claim. The only resemblance these chords have to the harmonic series is that the larger intervals are on the bottom. Other than that, these chords would be considered inharmonic as they do not conform to whole number multiples of the fundamental—in this case the fundamental of the triangle is a C_4-1/8-tone-sharp.

As fruitful as these spectral analyses are, *Silver Streetcar for the Orchestra* does not ask the performer to alter beater diameter. The piece does, however, ask for dampening of the triangle, shifting beater location, as well as altering where the triangle is being dampened. I chose to document the beater location on the

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[82] Coralie Diatkine, "Openmusic Documentation," Ircam - Centre Pompidou, http://support.ircam.fr/docs/om/om6-manual/co/Editor-Microintervals.html.

triangle in the same way I measured the different overtone characteristics with beater diameter. Figure 3.13 displays five different beating areas with illustrations of where the location exists on the triangle directly above each chord.[83]

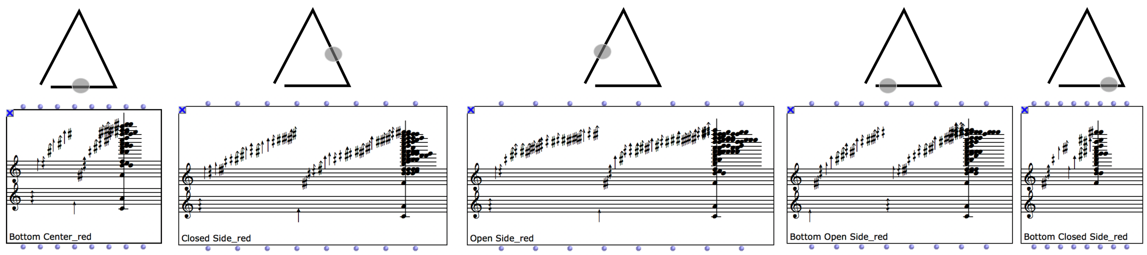

Figure 3.13: Comparison of notated spectral chords based on various striking positions. The illustrations above the chords mark the striking area with a grey circle.

To show how much the muting location can change the overtone characteristics of the triangle I recorded three different attacks; the beating location stays constant, however, the muting location changes along the open side of the triangle (see Figure 3.14 with the muting areas shaded in the illustrations above each chord).

[83] I used the same red beater (3/16″) to strike each area of the triangle.

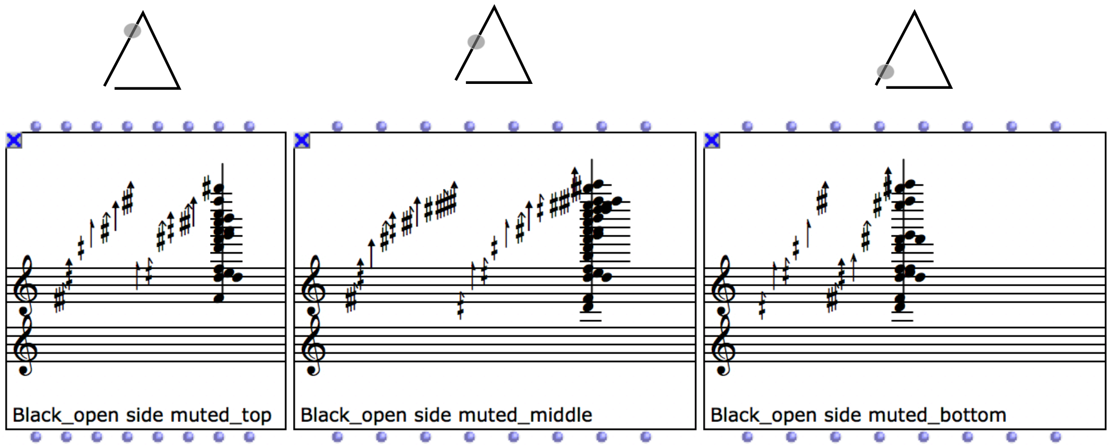

Figure 3.14: Comparison of notated spectral chords based on various muting locations—each struck at the center of the bottom of the triangle. The illustrations above the chords mark the muting location with a grey circle.

Though these analyses aim to illustrate the physical properties of the triangle, they also provide the answers as to why the spectrogram in Figure 3.11 behaves the way that it does. Throughout the course of a performance of this work, the performer will transition, at the very least, between different playing locations on the triangle. The act of moving the triangle beater will elicit a different response from the triangle much like how the chords in Figure 3.14 are so drastically different.

To demonstrate the result of one shift in the muting parameter, I recorded a forty-second excerpt of *Silver Streetcar for the Orchestra* in which my muting location traveled from the top of the left side of the triangle to the bottom. The resulting spectrogram is shown in Figure 3.15. Take note of the appearing and disappearing frequencies as the time on the x axis increases.

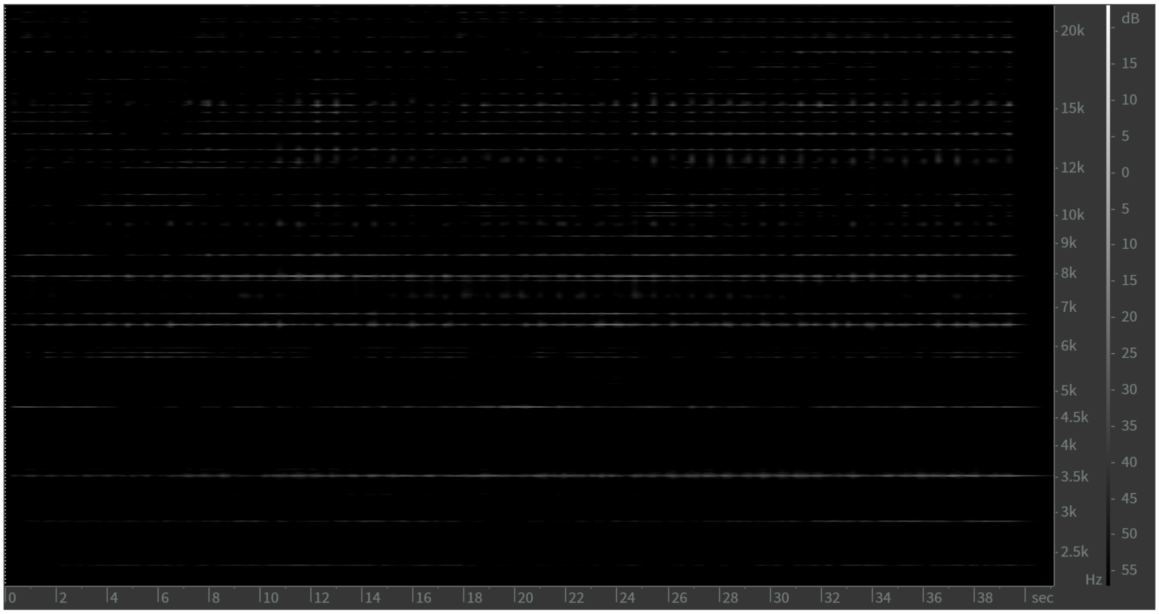

Figure 3.15: A forty-second excerpt displaying the spectral result of shifting the muting location from the top to the bottom of the open (left) side of the triangle.[84]

Acoustics

Often met with a cringe from program readers, *Silver Streetcar for the Orchestra*'s use of amplification is vital to its performance and reception. The presence of reverberation shifts the attention of listening to the overtones instead of a series of repeated articulations resulting in amplified aural interest. In conjunction with increased overtone presence, the amplified sound—to state the obvious—is louder in the space resulting in a heightened amount of reverberation.

[84] Take note that only frequencies between 2,000–20,000 Hz are displayed. This range displayed the most activity in terms of frequencies.

The presence of this reverberation allows the activated overtones to reinforce themselves. I have tested this hypothesis originally through a qualitative study. In this study, I recorded a performance of *Silver Streetcar for the Orchestra* in an anechoic chamber and selected a five-minute excerpt of the recording.[85] I then duplicated the excerpt and added artificial reverberation. This resulted in one dry (no reverberation) and one wet (with reverberation) recording of the exact same musical excerpt. Using this material, I designed a focus group study that featured multiple open-ended questions geared towards the perception and discrimination of two excerpts of the same musical material based on the presence or absence of reverberation.

Psychoacoustics

To better understand the effect of reverberation on the listener, I designed a focus group that probed the listeners to multiple facets of the performance. The results of the focus group study gave me insight to far more than the fact that the addition of reverberation altered the listening experience. The study aimed to address my original hypothesis that the presence of reverberation results in time that is perceived to move faster. To test this, I played both excerpts in succession—first the dry recording, then the reverberant recording—with a five-

[85] An anechoic chamber is a highly treated room that eliminates all sound reflections.

second pause between the excerpts. The participants were then given 20 minutes to fill out a questionnaire that probed their perceptions of both excerpts (see Appendix).

Out of 34 participants—each a music student with at least five years of music experience—17 agreed that the second recording (reverberant) felt shorter in duration, 2 felt the first excerpt (dry) was shorter, and 15 either were not paying attention to the duration or felt the excerpts were "pretty much the same" duration.[86] Testing this hypothesis with open-ended questions in a qualitative setting led to some additional insights. Nineteen students stated that the speed of articulations increased with the presence of the reverberation, and 2 students commented that the pitch of the triangle shifted with the presence of the reverberation. This latter observation is particularly surprising given that participants were not prompted to respond to changes in pitch between the excerpts.

The results of this study show a myriad of perceptual changes in response to the addition of reverberation to an auditory signal. Not only do the findings support my hypothesis that the presence of reverberation results in a perceived

[86] The participants were not given any prior instructions about what to listen for. The study was designed to receive general input on first impressions.

listening experience of shorter duration, but they also reveal perceived changes in both pitch and articulation speed.

In tandem with the effects of reverberation is the phenomenon of adaptation. When a triangle is struck, our attention focuses on the resonant metallic sound as it naturally decays in the space. The triangle's decay is not the only sound present, however, at the very onset of the triangle's tone is the brief metallic sound resulting from the beater hitting the triangle. Of course, this is needed to excite the metal for it to ring, but in most cases, the triangle is hit only once. In *Silver Streetcar for the Orchestra*, on the other hand, features quick and consistent triangle attacks. This, along with the subtle dampening of the triangle's resonance, brings this seemingly unnoticeable sound of the beater attack to the listener's attention. This now noticeable sound only holds our attention for a brief period of time due to the adaptation that takes place in our auditory system. Since the beater sound does not change—because the physical beater does not change—and the overtones are constantly changing, meaning new sounds appear in the texture throughout the piece, the sound of the beater is phased out of our consciousness. Because the phenomenon of adaptation relies so heavily on recognizing changes in a signal, the listener is drawn to the fluctuating presence of overtones throughout the work.

Conclusion

Silver Streetcar for the Orchestra features particles that call upon our perceptive capabilities. The vibrating media focused on the inharmonic nature of the triangle. This was supported by various spectral analyses of different parameters such as beater size, location, and muting location. The acoustic spectral particle of reverberation supports the unique overtones of the triangle. The presence of the microphone increases the audibility of the reverberation causing the listeners to have a longer and more pronounced exposure to the shifting overtones. Coupled with the presence of reverberation, the repeated sound of the beater against the triangle gets phased out of our consciousness allowing for more attention to be made to the changing overtones. The combination of these two psychoacoustic particles causes an increase in arousal for the listener resulting in their perception of time, pitch, and speed to fluctuate throughout the performance. These spectral particles combine to form the spectral atom of attention. This atom reflects the intention to call upon the audience's attention towards a repeated musical gesture. The challenges caused by the spectral particles on the audience's attention result in the illumination of the overtone characteristics of the triangle.

I am Sitting in a Room

General

One of Lucier's most famous pieces, *I am Sitting in a Room* (1970) bridges the gap between music and acoustical phenomenon. In his book, *Music 109: Notes on Experimental Music*, Lucier discusses an encounter with Edward Dewan at Brandeis University informing him of a lecture given by Amar Bose, the founder of one of the current leading audio equipment corporations in the world. In this lecture, Bose explained his use of recycling sound as a technique for testing loudspeakers.[87] The concept of *I am Sitting in a Room* is revealed through the process, initially conducted by Bose, of recycling sound, not only through the speakers but recycling within the room itself. What the recycling reveals is the audio phenomena concerning standing waves and sympathetic resonance. To explain what the repetitive act of recycling the sound through the room achieves, Lucier states:

> If the dimensions of a room are in a simple relationship to a sound that is played in it, that sound will be reinforced, that is, it will be amplified by the reflections from the walls. If, however, the sound doesn't "fit" the room, so to speak, it will be reflected out of phase with itself and tend to filter itself out. So by playing sounds into a room over and over again, you reinforce some of them more and more each time and eliminate others. It's a form of amplification by repetition.[88]

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[87] Alvin Lucier, *Music 109: Notes on Experimental Music* (Middletown, Connecticut: Wesleyan University Press, 2012), 88–91.
[88] Alvin Lucier and Douglas Simon, "Every room has its own melody," in Lucier, et al., *Reflections: Interviews, Scores, Writings*, 2nd revised ed. (Cologne: MusikTexte, 1995), 88.

I am Sitting in a Room consists of one person with at least one microphone and loudspeaker—although Lucier encourages performers to experiment with the placement and number of these devices. The reader of the text records a statement, either the one Lucier provides or one of their choosing, into the microphone(s). This recording is then played back into the room and the resulting playback is recorded. The newly made recording receives the same treatment in a feedback loop setting.[89] The repetition causes the original recording to undergo a process of filtration and conformation to the space until, eventually, the original recorded material becomes distorted. Once the process is finished, the original recording is filtered to the point of only projecting the resonant frequencies of the room. Even though Lucier's famous dialogue in the piece states "… I regard this activity not so much as a demonstration of a physical fact but more, as a way to smooth out any irregularities my speech might have," it is impossible not to experience the acoustic conformity of the room (see Figure 3.16).[90]

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[89] In this case, the feedback loop is the projection, recording of the projection, then projecting the most recent recorded material which, in turn, starts the loop over again.
[90] Lucier, Gronemeyer, and Oehlschlägel, 312.

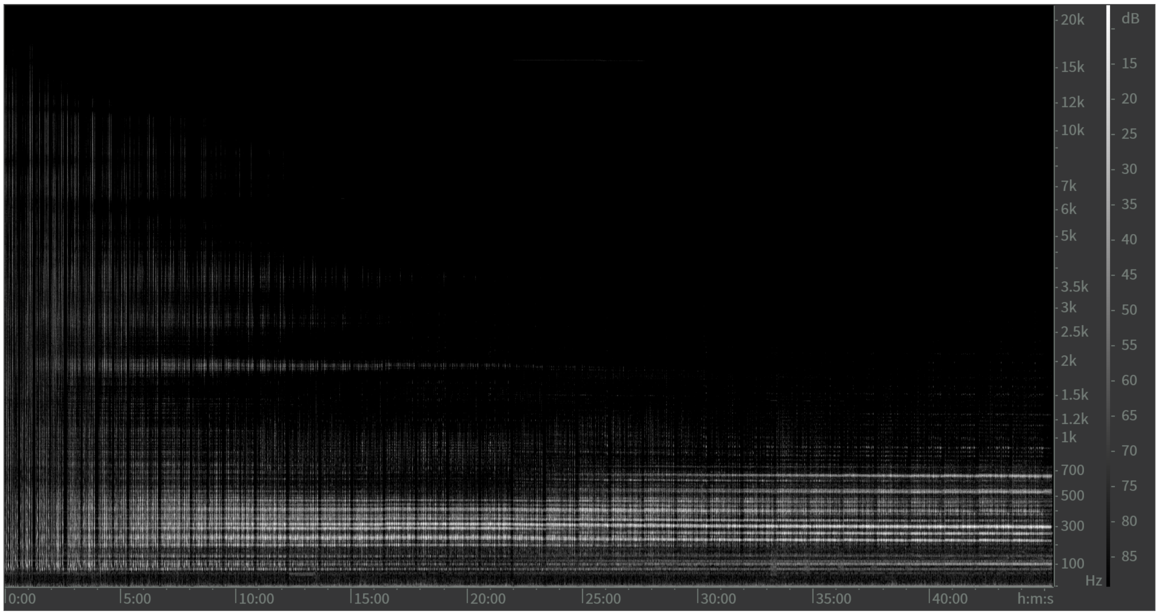

Figure 3.16: Spectrogram view of the entire performance of *I am Sitting in a Room* taken from the audio compact disc from Lovely Music.[91]

Psychoacoustics

Perhaps the least present spectral particle in *I am Sitting in a Room* is the psychoacoustic particle. However, recalling the concept of adaptation in the previous chapter can provide insight to how the piece operates. Though the experiments were done with very quick sound impulses, it was found that "when a sound is first [introduced], the neural spike rate in response to that sound is initially high, but rapidly declines."[92] Regarding this piece, the first introduced sound would be Lucier's initial recorded statement. If this statement

[91] Alvin Lucier, "I Am Sitting in a Room," in *I Am Sitting In A Room* (Lovely Music CD/LP, 1013, 1981/1990).

[92] Moore, 50. Originally published by: N. Y. S. Kiang, E. C. Moxon, and R. A. Levine, *Sensorineural Hearing Loss*, Auditory-Nerve Activity in Cats with Normal and Abnormal Cochleas (London: Churchill: G. E. W. Wolstenholme & J. J. Knight, 2008).

was recorded verbatim for the entirety of the piece, our neural response rates—synonymous with our interest level—would diminish with each repetition. Instead, the sound changes ever so slightly with every repetition. With each presentation of this altered sound comes a peak in neural response and consequently our interest for the entirety of the work.

Acoustics

I am Sitting in a Room exists solely because of the filtering process that occurs within a space—in fact, the space is far more active in this piece than the human performer. This is because dimensional spaces—spaces that have boundaries whether they are walls, floor, or ceiling—possess resonance modes. These modes exist in the form of axial, tangential, and oblique (defined in Chapter 2). The effects these modes have on sound is simply a matter of coincidence. If a frequency that is present in the sound source coincides with a frequency present in one of the room modes, that particular frequency will be reinforced. Consequently, if a frequency in the sound source does not coincide with a room mode, the frequency will have nothing to reinforce its presence and will eventually be phased out of the sound source. The operative feedback-loop present in this piece will, over time, reinforce the room modes.[93]

To demonstrate the effect that room modes have on sounds, I have made a performance of *I am Sitting in a Room* in a classroom—aptly titled *I am Sitting in a Classroom*.[94] I chose this classroom because it is a simple rectangular space with easily defined dimensions. Figure 3.17 displays a spectrogram of the entire performance. It is easy to see many of the initial frequencies become filtered out completely as the piece progresses.

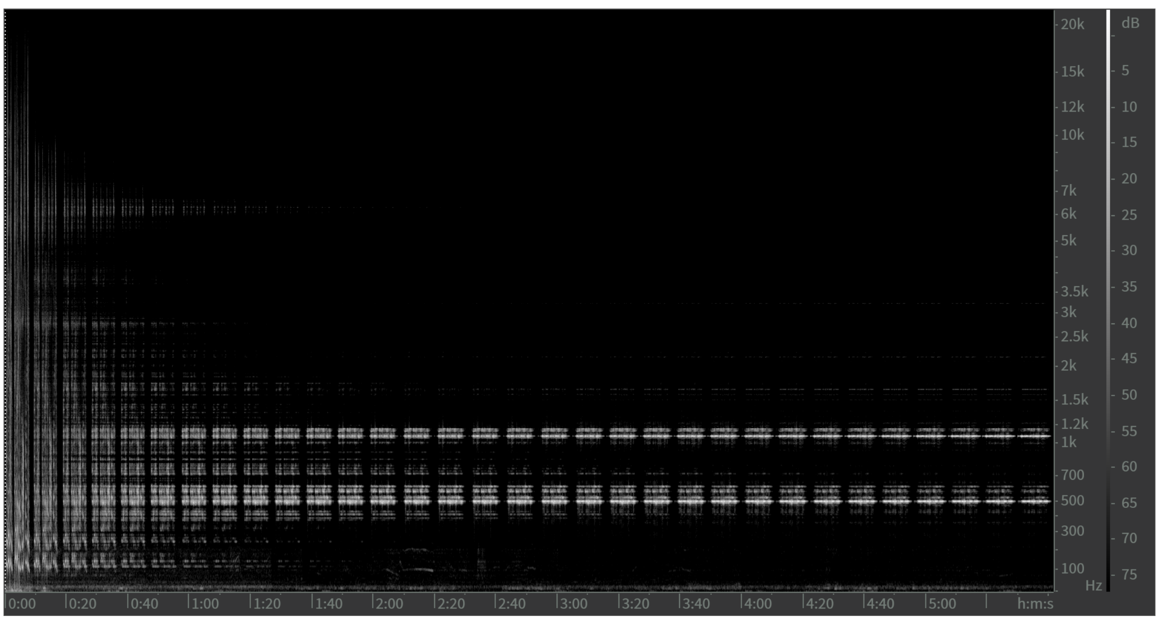

Figure 3.17: Spectrogram view of my recording of *I am Sitting in a Classroom*. The performance took place in room 140 in the University of Louisville's School of Music.

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[93] The room modes that will be reinforced will only consist of the frequencies present in the original recording. The process is not designed to introduce/create new frequencies, only to filter the frequencies already present.

[94] Performed in room 140 in the University of Louisville's School of Music. I maintained the same number of repetitions (32) that Lucier made in his original *I am Sitting in a Room*.

As can be implied, the frequencies present in the final repetition is far from random. Using the universal modal frequency equation (shown below), I was able to plug the dimensions of the classroom into the formula to reveal the frequencies of the modes of the space.[95]

$$f_{xyz} = \frac{c}{2}\sqrt{\left(\frac{x}{L}\right)^2 + \left(\frac{y}{W}\right)^2 + \left(\frac{z}{H}\right)^2}$$

Using this equation, I found that the first axial mode for L, W, and H to be 22.28 Hz, 21.03 Hz, and 53.59 Hz, respectively.[96] These modes operate in the same manner as the harmonic series in the sense that the first mode acts as the fundamental, and each subsequent mode is a whole number multiple of the first. Figure 3.18 plots the first thirty frequencies (in Hz) of the axial, tangential, and oblique modes.

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[95] Where f is frequency, c is speed of sound, and L, W, and H are length, width, and height, respectively. Howard and Angus, 334.

[96] The first of the two tangential modes are 30.64 Hz for L and W, and 57.57 for W and H. The first oblique mode is 61.73 Hz.

	Axial			Tangential			Oblique
Mode	**L**	**W**	**H**	**L+W**	**W+H**	**L+H**	**L+W+H**
1	22.28	21.03	53.59	30.64	57.57	58.04	61.73
2	44.56	42.06	107.18	61.28	115.14	116.08	123.46
3	66.84	63.09	160.77	91.92	172.71	174.12	185.19
4	89.12	84.12	214.36	122.56	230.28	232.16	246.92
5	111.4	105.15	267.95	153.2	287.85	290.2	308.65
6	133.68	126.18	321.54	183.84	345.42	348.24	370.38
7	155.96	147.21	375.13	214.48	402.99	406.28	432.11
8	178.24	168.24	428.72	245.12	460.56	464.32	493.84
9	200.52	189.27	482.31	275.76	518.13	522.36	555.57
10	222.8	210.3	535.9	306.4	575.7	580.4	617.3
11	245.08	231.33	589.49	337.04	633.27	638.44	679.03
12	267.36	252.36	643.08	367.68	690.84	696.48	740.76
13	289.64	273.39	696.67	398.32	748.41	754.52	802.49
14	311.92	294.42	750.26	428.96	805.98	812.56	864.22
15	334.2	315.45	803.85	459.6	863.55	870.6	925.95
16	356.48	336.48	857.44	490.24	921.12	928.64	987.68
17	378.76	357.51	911.03	520.88	978.69	986.68	1049.41
18	401.04	378.54	964.62	551.52	1036.26	1044.72	1111.14
19	423.32	399.57	1018.21	582.16	1093.83	1102.76	1172.87
20	445.6	420.6	1071.8	612.8	1151.4	1160.8	1234.6
21	467.88	441.63	1125.39	643.44	1208.97	1218.84	1296.33
22	490.16	462.66	1178.98	674.08	1266.54	1276.88	1358.06
23	512.44	483.69	1232.57	704.72	1324.11	1334.92	1419.79
24	534.72	504.72	1286.16	735.36	1381.68	1392.96	1481.52
25	557	525.75	1339.75	766	1439.25	1451	1543.25
26	579.28	546.78	1393.34	796.64	1496.82	1509.04	1604.98
27	601.56	567.81	1446.93	827.28	1554.39	1567.08	1666.71
28	623.84	588.84	1500.52	857.92	1611.96	1625.12	1728.44
29	646.12	609.87	1554.11	888.56	1669.53	1683.16	1790.17
30	668.4	630.9	1607.7	919.2	1727.1	1741.2	1851.9

Figure 3.18: The first 30 room modes, in Hz, of room 140 in the University of Louisville's School of Music.

Using Figure 3.18, we can compare the frequencies present in the last repetition of *I am Sitting in a Classroom* to see what modes had the most effect on my original sound source. The final repetition included frequencies 3249, 2159, 1660, 1586, 1514, 1227, 1157, 1140, 1104, 1076*, 1054, 1002, 618, 590, 578, 534, 506*, 496*, 478, and 431.[97] Of the present frequencies, if within 10 Hz of one of the modes in Figure 3.18, I shaded the cell grey to highlight how many modes coincided with the final repetition of my recording.[98]

Originally, I had planned to reverse-engineer the recording Lucier did, but there is far more to the process than figuring out the frequencies. The idea of being able to predict the outcome of this piece attracted the theorist in me, but the inability to do so fuels the unknown that is attractive to most composers. Instead of seeking a definitive end result and achieving said result through performance, I think the ability to calculate room modes could be used in the planning stages of future performances. I am certain that a composer such as Lucier could meticulously plan each inflection of their voice in accordance with the dimensions of a particular space, but to what end? At best they would end up with a series of frequencies, much like Figure 3.18; they may even plot the table over a timeline if they felt particularly specific. What they cannot predict, however, is the pulsing of the frequencies, how quickly frequencies decay—and even appear—when frequencies will start to strengthen, etc. This leaves both the

[97] Each frequency—represented in Hz—is an approximation based off of the spectrogram image. The asterisks mark the strongest frequencies.
[98] Stopping at 30 modes, many of the present frequencies were unable to be matched and calculated. For instance, 3249 Hz is the 108th mode of the L+W tangential mode, 2159 Hz is the 35th mode of the oblique mode, etc.

composer, as well as the audience, in blissful ignorance until the final repetition concludes.

Vibrating Media

As a vessel, *I am Sitting in a Room* takes us—both Lucier as well as the audience—on a journey to the unknown. Lucier's initial concept was to smooth out the inconsistencies of his voice by letting the room take over. Each performer of this piece brings with them a unique harmonic structure of their voice. From their particular inflection habits, formant structure, and tone, each performance will produce a unique outcome—even if performed in the same space.

It has also led Lucier to explore this concept further by changing the sound source as well as the filtering space. His *The Exploration of the House* (2005) utilizes fragments of Beethoven's *The Consecration of the House* overture. Just like in *I am Sitting in a Room*, the orchestra records an excerpt of the piece and the recording undergoes the same filter-loop until the room's characteristics take over. Then a new excerpt is recorded, and the process repeats for a total of seventeen excerpts. On a much smaller scale, figuratively as well as literally, *Nothing is Real (Strawberry Fields)* (1990) features a similar concept but challenges our pre-conceived notion of what constitutes a performance space. Focusing on the filtering qualities of a space, the piece askes the performer to record small fragments from the Beatles' *Strawberry Fields*. The performer then plays the recording of collected fragments through a speaker inside of a teapot. Though the looping scheme is gone, the filtering characteristics of the room—in this case the room being a teapot—are exploited in a rather stark binary approach rather than the gradual shift that occurs in *I am Sitting in a Room*.

Conclusion

I am Sitting in a Room features two active spectral atoms: attention and filtration. The attention atom calls upon the process of the piece as whole. Similarly to *Silver Streetcar for the Orchestra*, this piece requires repetition in order to function. The repeated material confronts our adaptive abilities through subtle change in each repetition. This subtle change is a result of the room's filtering characteristics (the acoustic spectral particle). The filtering capabilities of the room reveal the coincident frequencies between the vibrating media (the initial sound source) and the room. When combining the three particles together, it is clear that, in addition to the attention atom, the filtration atom plays a crucial role in this piece.

Still and Moving Lines of Silence in Families of Hyperbolas

General

Originally for singers, players, dancers, and unattended percussion in 1973–1974, *Still and Moving Lines of Silence in Families of Hyperbolas* was re-written in 1984 to feature three parts. Part I, Numbers 1–4, features the clarinet, female voice, flute, and horn each accompanied by either one or two pure wave oscillators; Part II, Numbers 5–8, is written for the marimba, xylophone, glockenspiel, and vibraphone each accompanied by one or two pure wave oscillators; Part III, Numbers 9–12, is written for viola, violin duet, violoncello, and violin solo each, again, each accompanied by one or two pure wave oscillators.[99] In each part, the four instruments are set up across the stage with loudspeakers on either side of the group.

Vibrating Media

At first glance it would appear that *Still and Moving Lines of Silence in Families of Hyperbolas* features closely tuned sounds much like how *Twonings* is constructed. Lucier states, however, that the spatiality in which the pure-wave oscillators propagate is the operative force of the work. In an interview with Douglas Simon, Lucier describes a scenario regarding sound reinforcement and elimination:

> You know that if you have a simple sound wave and a reflective surface, under certain circumstances, depending on the frequency of the sound and the distance between the source of the sound and the reflective surface, you can create standing waves. If the wavelengths of the frequencies are in simple proportion to the size of the room, then the sound bounding off a reflective surface returns in synchronization with another wave as it's going

[99] Each Number in *Still and Moving Lines of Silence in Families of Hyperbolas* is an individual movement. There are twelve distinct movements (Numbers) in the entirety of the piece.

> out, and it amplifies itself. It's as if the reflective surface were a second source at the same frequency which interferes constructively with the first to produce a rise in amplitude. If the distance between the sound source and the reflective surface is not in simple proportion to the wavelength, then you get destructive interference; as the wave bounces back, it interferes with the wave that goes out. Under ideal circumstances, if it were hundred and eighty degrees out of phase, it would attenuate the outgoing wave and completely eliminate it. You never get an ideal situation in a room because you're surrounded by reflective surfaces and because sound propagates all over, it doesn't go out in a line, it goes out in concentrically, so you get reflections from all over. And if it's a highly reflective room, it's as if there were a great many loudspeakers or sound sources all over the room, and the standing waves become very complicated.[100]

It is precisely this constructive and destructive interference that when combined with the space in which the piece exists, it gives further insight to the title of the piece. In the original version of this piece—consisting of dancers—where the choreography asked the visual artists to dance and move along the troughs in the sound field as the piece was performed. The silent lines mentioned in the title, both moving and still, are formed due to the nature in which sound exits the loudspeakers. For example, if two loudspeakers were producing the same sine tone, there will be places where the source sounds overlap but at different points in their cycle. Moreover, it will take a longer time for the wave produced by one speaker to reach the wave produced by the other speaker. What results is that the two sine tones will be out of phase cancelling each other out (destructive interference) causing a point of silence; concurrently, the time difference could

[100] Lucier, Gronemeyer, and Oehlschlägel, 152.

cause the phase of both waves to coincide exactly resulting in a doubling in amplitude creating a peak. In fact, "there's an infinite number of these points in families as you move further out from the loudspeakers and that they form curves, specifically hyperbolas."[101]

Lucier expands on the concept of these families of silent and loud points by detuning one of the sound sources. Because one frequency is slower—fewer cycles per second—it causes a continuous change in the location of the silent and loud families within the space. The loud and silent points begin to spin around the room in elliptical patterns. These patterns are directionally dependent and always spin towards the lower sound-source.[102] To demonstrate this result even further, Lucier performed a version of this piece in which he placed snare drums throughout the space. When the snares are activated on the drums, they will resonate when the sound crest (constructive amplitude increase) reaches the snare drum. The sounds can then be traced across the drums in the space to show direction and speed of the moving families. In fact, the sounds can be so predictable that Lucier experimented with the snare drums by making "twos against threes, sevens against eights, all kinds of rhythmic patterns, by simply changing frequencies."[103]

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[101] Ibid., 154.
[102] Ibid.
[103] Ibid., 158.

The parts are organized in a symmetrical fashion according to the role the instruments play in conjunction with the pure wave oscillators. Parts I and III feature the acoustic instruments shifting microtonally in pitch against the pure wave oscillator. The way each instrument shifts microtonally, however, is unique to each Number (instrument). Numbers 5–8 (Part II) on the other hand, are written for fixed-pitch instruments and therefore cannot shift microtonally against a pure wave oscillator. Instead, the instruments shift in their rate of attack throughout each Number.

Acoustics

Parts I and III, as mentioned prior, are written so that the acoustic instruments play different pitches in various relations to the fixed pure-wave oscillators. This gives Lucier the ability to control how the sound moves through the space. For example, in Number 1, for clarinet, the oscillator is tuned to 294 Hz and panned to the right speaker, relative to the audience. The clarinetist is asked to play sixteen long-tones. The first eight are at frequencies below the pure-wave oscillator that rise in pitch with each tone eventually reaching unison at the ninth; the remaining pitches continue to rise in frequency above the pure-wave oscillator with each pitch.[104] This organization creates a continuously evolving

[104] Alvin Lucier, *Still and Moving Lines of Silence in Families of Hyperbolas*, (Fankfurt am Main: Alvin Lucier, distributed by Material Press, 2013).

geography: at the start of the piece, the families of loudness and silence spin in elliptical patterns towards the direction of the clarinet (counterclockwise). As the frequency increases with each subsequent clarinet tone, the spinning patterns begin to slow down, still moving in their counterclockwise direction until the point of unison in which the spinning will stop. The tenth tone, the clarinet playing a frequency above the pure-wave oscillator for the first time in the piece, results in a flipping of the spinning pattern. Now that the frequency in the loudspeaker is lower than the clarinet, the sound will start to spin clockwise towards the speaker. With each subsequent pitch the clarinet plays, the spinning will increase in speed until the end of the piece.

With each number, in parts I and III, a new organization to the spinning phenomenon is introduced to the audience. The instruments used in part II, on the other hand, do not allow Lucier to manipulate the geography of sound in the same way. Since each instrument has a fixed pitch—played in a sequence of sixteen series that vary in tempo—and the pitch does not change within each number, the spinning that is generated in each number stays consistent. Part II, instead, focuses on polyrhythmic applications nested in between two numbers that feature the singular spinning phenomenon as discussed previously. This part consists of marimba, xylophone, glockenspiel, and vibraphone, respectively, from stage left to right.

Part II is book-ended by Numbers 5, for marimba, and 8, for vibraphone. Number 5 features a pure-wave oscillator tuned 1/2 Hz lower than the frequency of the marimba—located stage left—causing a beating rate of one beat every two seconds. This oscillator is routed to the right channel which results in a slow clockwise spinning phenomenon. Consequently, Number 8 consists of an oscillator tuned 2 Hz higher than the vibraphone—located stage right—routed to the left speaker causing a beating rate of two beats every second. This combination will produce the same clockwise spinning as featured in Number 5 despite the flipped roles of the two sound sources.

The inner-two Numbers, 6 and 7 for xylophone and glockenspiel, respectively, both utilize two oscillators to create what Lucier describes as "3-dimensional rhythmic shapes in the room."[105] In the xylophone Number, the oscillators are tuned 2 Hz below (right channel) and 3 Hz above (left channel) the xylophone pitch. These settings result in a myriad of beating phenomena. The two oscillators alone differ by 5 Hz and will cause a beating rate of 5 beats per-second and will be perceived to spin in a clockwise motion around the space. The addition of the xylophone complicates the situation: because the xylophone's frequency is both 2 Hz higher than the right oscillator and 3 Hz lower than the left oscillator, a polyrhythm of 3/2 will arise. Furthermore, this creates a unique

[105] Ibid.

geography of the sound within the room causing it to spin in two different clockwise patterns at two different speeds.

Because the player is asked to strike the xylophone at a steady rate, changing speed with each subsequent series, the phenomena are in constant flux. Because of the rapid decay of the xylophone, its pitch is not present 100% of the time meaning that there is a small gap of time between each attack where the spinning sound reverts back to the singular spinning phenomenon caused by the lone oscillators.[106] The listeners, then, are bombarded with an ever-changing atmosphere in which the rate alternates between increasingly faster and slower in a wedge-like shape.[107]

Number 7, for glockenspiel, follows a similar design. Unlike the other three works in Part II, Number 7 produces a clockwise pattern of spinning. With oscillators tuned 5 Hz below and 4 Hz above the glockenspiel's frequency. Without the glockenspiel, a beating rate of 9 beats per-second is produced. With the addition of the glockenspiel's pitch, instead of the polyrhythm of 3/2 created with the xylophone, a polyrhythm of 5/4 is produced.

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[106] This point is made in addition to the intentional xylophone break of 5–10 seconds between each of the sixteen series.

[107] "Starting at [a metronome marking of] 176 [bpm], the player alternately steps up and down 8 markings at a time, arriving at [a metronome marking of] 240 [bpm] by the 16th series." This creates the pattern of 176, 184, 168, 192, 160, 200, 152, 208, 144, 216, 136, 224, 128, 232, 120, 240. Ibid.

Aside from experiencing frequencies five-times as high as the ones heard in the xylophone Number, the audience is subjected to less bombardment of changing room geographies. The natural amplitude envelope of the glockenspiel features a far longer decay time than that of the xylophone resulting in less opportunity for a break in sound between attacks.[108] In fact, the glockenspiel in Number 7, both due to speed of attacks and amplitude envelope, creates an almost complete sustain in frequency.

Psychoacoustics

Still and Moving Lines of Silence in Families of Hyperbolas interacts with three different perceptual phenomena. The most obvious aural effect caused by this piece is its interaction with the critical band. Each of the twelve Numbers throughout the entirety of the piece focus on close tunings between a static pure-wave oscillator and an acoustic instrument—whether that instrument is fluctuating in pitch or staying constant. A less obvious psychoacoustic focus is the perceptual discrimination of both tempo and frequency. Parts I and III feature acoustic instruments that subtly change pitch throughout their respective

[108] The amplitude envelope refers to, usually in milliseconds, the amount of time it takes the sound to reach max amplitude from silence, length of decay time to reach the sustain amplitude, length of sustain, and the amount of time from release to silence. For example, the striking of a marimba bar features a near-instantaneous attack and a long decay as the sound decays. Because of the percussive nature of the marimba, the bar cannot physically sustain and thus is void of any sustain or release envelope information.

movement. I am interested in the audience's ability to perceive the frequency changes these instruments make. Part II, on the other hand, consists of instruments that change in tempo throughout their respective movements. Likewise, I am interested in if the audience can detect the tempo changes made by the performers.

What is interesting about the instruction given by Alvin Lucier in Parts I and III is that, aside from the frequency specificity of the pure-wave oscillator, the performer is only given text instructions. For instance, Number 1, for clarinet, presents the player with the instructions to "start several cycles below D at 294 cps; then step up, with each succeeding tone, a few cycles at a time, reaching unison by the 9th tone, continuing upward, stopping several cycles above the pure wave by the 16th tone."[109] To take Lucier's directions literally, this would result in a frequency range of 291–297 Hz—a change in .375 Hz over the course of sixteen tones. The critical bandwidth is understood to be a filter, rectangular in shape, called the equivalent rectangular bandwidth. The width of this filter can be calculated with the formula:

$$\text{ERB} = \{24.7 \times [(4.37 \times f_c) + 1]\}\ \text{Hz}$$

[109] Ibid.

where f_c is the center frequency of the filter in kilohertz (kHz) and ERB as the equivalent rectangular bandwidth in Hz. When plotting the oscillator frequency of Number 1 (294 Hz) into this formula, an ERB of 56.43 Hz results.[110]

With the success of Number 1, I decided to trace whether or not the pitch manipulations made by the performer in each individual movement fell within the critical bandwidth as well. Figure 3.19 displays the critical bandwidth as well as the oscillator tuning(s), the center frequency, the boundaries above and below the center frequency, and if the pitch manipulations of each Number occur within the critical bandwidth.[111] I chose to label the single oscillators as the center frequency due to their stasis throughout each of the Numbers. For pieces that utilize two oscillators, I calculated the center frequency as the average between the two of them—justified by their stasis within their respective movements. The pitch manipulations made by the performers, when compared to the center frequencies, still fell within the critical bandwidth. This figure makes clear the idea that the critical bandwidth is vital to the success and performance of this piece.

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110 Howard and Angus, 85.

111 When deciding if the pitch alterations occurred within the critical bandwidth, I used Lucier's instructions exactly—"a few" was interpreted as three and "several" was interpreted as less-than ten.

	Oscillator 1 (Hz)	Oscillator 2 (Hz)	Center Frequency (kHz)	Critical Bandwidth (Hz)	± From Center Frequency (Hz)	Stays Within CB
Number 1 Clarinet	294	N/A	0.2940	56.4341	28.2170	Yes
Number 2 Voice	508	538	0.5230	81.1521	40.5760	Yes
Number 3 Flute	437	443	0.4400	72.1932	36.0966	Yes
Number 4 Horn	233	N/A	0.2330	49.8498	24.9249	Yes
Number 5 Marimba	138.1	N/A	0.1381	39.6064	19.8032	Yes
Number 6 Xylophone	423.3	428	0.4258	70.6604	35.3302	Yes
Number 7 Glockenspiel	2484	2493	2.4885	293.3062	146.6531	Yes
Number 8 Vibraphone	351	N/A	0.3510	62.5866	31.2933	Yes
Number 9 Viola	196	N/A	0.1960	45.8560	22.9280	Yes
Number 10 Violin Duet	554	N/A	0.5540	84.4982	42.2491	Yes
Number 11 Cello	82.4	N/A	0.0824	33.5942	16.7971	Yes
Number 12 Violin (solo)	2786	2802	2.7940	326.2816	163.1408	Yes

Figure 3.19: Range of frequency deviation for Numbers 1–12 of *Still and Moving Lines of Silence in Families of Hyperbolas* and their relationship to the critical bandwidth.

In addition to the exploitation of the critical bandwidth, I think our ability to detect a change in frequency, referred to as frequency discrimination, is also paramount to this work. In his *The Perceptual and Auditory Implications of Parametric Scaling in Synthetic Speech*, Robert Mannell summarizes that "125–2,000 Hz [the frequency difference threshold] is constant at about 3 Hz. It rises to about 12 Hz by 5,000 Hz, 30 Hz by 10,000 Hz, and 187 Hz by 15,000 Hz."[112] Essentially, what this tells us is that any change in pitch done by a performer—since we are

[112] Robert Mannell, *The Perceptual and Auditory Implications of Parametric Scaling in Synthetic Speech*, (Unpublished PhD diss., Macquarie University, 1994), Chapter 2.

dealing with frequencies that are below 5,000 Hz—that is less than 3 Hz will go unnoticed by the listener.

The significance in this lies in the fact that, for Numbers 1, 3, and 10, the listeners are unable to notice that the player is slightly changing pitch.[113] Though the listeners are unable to detect the changes in pitch that are occurring the effects on their critical band still change with each new note. The audience is exposed to changing sounds without realizing that the sounds are actually changing.

Part II, on the other hand, calls on our ability to detect changes in tempo, or tempo discrimination. Kim Thomas conducted a study that measured how much change, in both slow (43 beats per minute [bpm]) and fast (75 bpm) tempos, is necessary before a change in bpm is detected. What she found was that a change of 3.28 bpm change is necessary to notice an increase from a slow to fast tempo; a 6.30 bpm change is necessary to notice an increase from an initial fast tempo; a 2.70 bpm change is necessary to notice a decrease from an initial slow tempo; and a 6.31 bpm change is necessary to notice a decrease from a fast tempo. Furthermore, she discovered that these changes, though noticeably

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113 Numbers 9 and 11 feature changes that straddle the line of perceptibility of change, though entirely possible. This results in over half of the possible Numbers—of the sixteen Numbers, only the eight from Parts I and III present changing pitches—where the audience is unable to notice the process of change throughout the Number.

different depending on initial tempo, are consistent with the ratio of change predicted by Weber's law.[114]

The question is whether or not the audience is able to notice the performer changing tempo between each series. Number 5 consists of tempo changes of 4 bpm, starting at 30 bpm and stopping at 90 bpm; Number 6, as mentioned earlier in this section, starts with a bpm of 176 and makes increasingly larger tempo changes as the series commence until reaching 240 bpm; Number 7 mirrors the nature of Number 2 making increasingly smaller tempo changes until reaching 320 bpm; Number 8 begins with a tempo of 150 bpm and decreases by 6 bpm until its conclusion at 60 bpm. Numbers 6 and 7 feature far too drastic of tempo changes to be considered.[115]

Numbers 5 and 8, however, both have consistent tempo changes. When applying Thomas's findings—an average of 3.28 bpm change is necessary to notice the increasing tempo—to Number 5, the results are inconclusive: this particular Number exceeds her testing variables by starting too slow and ending too fast. However, if we consider the research done by Mark Ellis, the data falls

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[114] Weber's law states that the change in a stimulus that will be just noticeable is a constant ratio of the original stimulus. Thomas, 18; "Weber's Law," in *Encyclopædia Britannica* (Encyclopædia Britannica, inc., 2016).

[115] However, the beginning two series of Number 6 and the final few series of Number 7 could fall into the range of imperceptibility.

more into place.[116] Figure 3.20 is taken from his study on the thresholds for detecting tempo change and shows the per-cent change needed to detect a change in tempo both speeding up and slowing down.[117] Beginning his testing at 48 bpm, an inference must be made to the leftward continuation of his graph to account for Number 5's beginning tempo of 30 bpm.

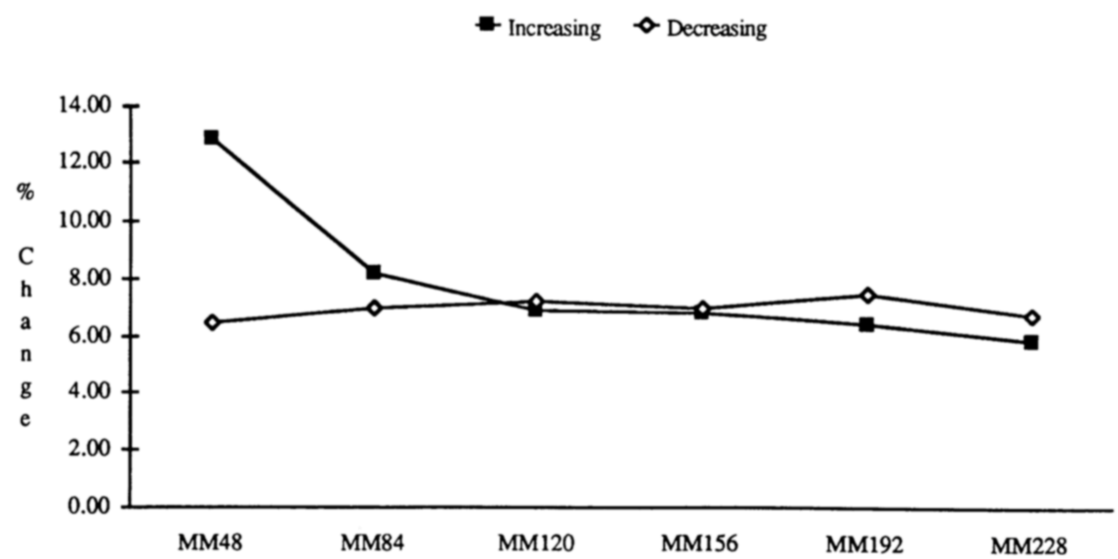

Figure 3.20: Chart of tempo discrimination. Percentage change is marked on the y-axis and tempo on the x-axis. Solid square plots represent data on increasing tempo and open diamonds represent data on decreasing tempo.

Figure 3.21 traces the tempo changes, accompanied with their per-cent of change, in Numbers 5 and 8 in order to compare to Ellis's data in Figure 3.20. When looking at the per-cent of change in Number 5—comparing specifically what is charted in Figure 3.20—the data falls well under the threshold

[116] Still starting too slow, the rest of the range is covered. An inference can be made to the leftward continuation of Figure 3.13.
[117] Ellis, 167.

represented by the solid boxes on the graph that was discovered by Ellis.[118] Concurrently, while looking at the data for Number 8—now referencing the data points on Figure 3.20 represented by open diamonds—every series falls under the threshold of change. It is, however, interesting to note how close the per-cent of change going into series 16 (in Number 8) falls to the threshold.

Number 5			**Number 8**		
Series	Beats-per-minute	% Change	Series	Beats-per-minute	% Change
1	30	13	1	150	3
2	34	12	2	144	3
3	38	11	3	138	3
4	42	10	4	132	3
5	46	9	5	126	3
6	50	8	6	120	3
7	54	7	7	114	4
8	58	7	8	108	4
9	62	6	9	102	4
10	66	6	10	96	4
11	70	6	11	90	4
12	74	5	12	84	5
13	78	5	13	78	5
14	82	5	14	72	6
15	86	5	15	66	6
16	90	4	16	60	7

Figure 3.21: The per-cent of change in bpm between each series in Numbers 5 and 8.[119]

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118 Though only the tempos of series 6–16 in Number 5 are represented in Figure 3.13, it is safe to assume that series 1–5 conform to the same results as series 6–16.

119 Per-cent of change was calculated by dividing the difference of bpm change by the previous series' bpm. For example, in Number 5, the per-cent of change between series 1 and 2 was calculated by dividing 4 by 30 resulting in a change of 13%. Each percentage was rounded to the nearest whole-number.

Conclusion

Also featuring two spectral atoms, *Still and Moving Lines of Silence in Families of Hyperbolas* focuses on both attention and tuning. Much like *Silver Streetcar for the Orchestra*, and *I am Sitting in a Room*, *Still and Moving Lines of Silence in Families of Hyperbolas* requires repetition to function. The attention atom relies heavily on our adaptive abilities in recognizing the change between repeated segments throughout the piece. This change is measured in tempo and frequency discrimination and, coupled with adaptation, act as the psychoacoustic particles of the piece. The acoustic and vibrating media particles work in tandem in that the physics of the sound wave speed (vibrating media particle) cause a spatial spinning effect (acoustic particle) for the audience. The tuning atom occurs mainly from the psychoacoustic particle through exploitation of the subtle shifts in pitch of the instruments against the static pure wave oscillator(s).

CHAPTER 4

HEREIN LIES THE SPECTRAL ATOM

Summary

It is uniquely constituted for each piece, using one or more of the spectral particles, to expose the piece's spectral atom. In our discussion on *Twonings*, I have identified the acoustic particle as tuning systems, the psychoacoustic particle as the beating caused by our critical bandwidth, and the vibrating media particle as the purity of the cello harmonics against the inharmonic rigidity of the piano's tuning system. These three spectral particles combine into the spectral atom of tuning. This atom supports Lucier's intent, as well as the core issue of this piece: the exploitation of these tuning inconsistencies in every possible way. His decision to use the piano, an instrument that is both inharmonic as well as explicit in its tuning, and the cello, an instrument consisting of four Pythagorean monochords, allowed him to easily exploit this atom. Lucier also exhibits a great deal of control in his choice of range. Of the minimum and maximum frequencies heard throughout the piece, the differences between the two instruments never fall outside of our critical bandwidth.

Silver Streetcar for the Orchestra utilizes different particles to achieve its effect. In terms of vibrating media, this piece exploits the non-pitched characteristic tuning of the percussive triangle. The acoustic particle brought light into the justification for amplifying the triangle by increasing the reverberation levels in the performance. The acoustic particle operates in tandem with the psychoacoustic particle as the added reverberation contributes to the listener's perception of time and arousal throughout the performance. Therefore, the repetition that exposes the complex harmonic series, while simultaneously distorting our perception of time, justifies classifying the spectral atom of this piece as attention.

I am Sitting in a Room features two spectral atoms, unlike the piece's mentioned thus far. The psychoacoustic particle, though weak in this work, called upon our adaptation capabilities. The acoustic particle consisted of the filtering effects of the room in which the piece is performed. The vibrating media particle doubles as a compositional choice in this work: the initial sound source—whether from a voice or an orchestra—will produce a unique outcome regardless of the space—even if the space is a teapot. Because the piece would not function without the acoustic processing of the sound source, the spectral atom of *I am Sitting in a Room* is labeled as filtration. However, the holistic process governing this piece recalls the performance process of *Silver Streetcar for* *the Orchestra*. In both cases Lucier can capture the audience's attention for an extended period of time while repeating the same musical material. Therefore, the attention atom is also prevalent in *I am Sitting in a Room*.

Still and Moving Lines of Silence in Families of Hyperbolas also features multiple spectral atoms. The vibrating media particle is the pure-wave oscillators and their relationship to the added acoustic instruments. The psychoacoustic particles present in this piece are our perception of closely tuned frequencies and our ability to discriminate changing frequencies and tempi. The former psychoacoustic particle directly relates to the acoustic particle: an acoustic spinning of sound throughout the space resulting from the frequency differences. The combination of these particles presents us with two spectral atoms: tuning and attention.

Why is this important?

None of these spectral atoms—tuning, attention, and filtration—exist by happenstance. Whether a work features a singular atom or multiple, Lucier intentionally exploited these atoms through the creation of his music. This elevates his works, as well as his compositional approach, out of the experimental and minimalistic pigeonholes that his music currently lives. Currently, the existing discussions of Alvin Lucier's music focus on the ideas behind it. Even in his own text, *Music 109: Notes on Experimental Music*, he gives accounts of techniques and ideologies used by experimental composers, himself included.[120] The growing work on his ideologies has not been matched with analyses of his music. This is not to say that he and his work have received little attention; in fact, there have been multiple interviews and even a video documentary that focus on the ideas and thoughts that Lucier has contributed to the field of composition.[121] This thesis is designed as an attempt to offset this research by showing the analytical potential that his music possesses.

Outside the realm of analysis, the insights uncovered in this thesis inform performance practices as well. I hope this thesis influences performers to take Lucier's music on a more serious level. Furthermore, a performer can prepare a more informed performance of the work with the added understanding of the goal of the piece. This transfers into the other pieces in this thesis as well—even to the rest of his works. With increased understanding of Lucier's objectives, a performer is more likely to realize the music closer to his intentions.

Further Research

Because this thesis only addresses four of Lucier's works, the next step is to analyze more of Lucier's music for its application of spectral particles.[122] By

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[120] Lucier, *Music 109*.

[121] Lucier, Gronemeyer, and Oehlschlägel.

[122] The task of deciding how to label the spectral particles has been particularly challenging. When introducing a new analytical concept, the labels must be clear, precise, and effective. The labeling of particles in this thesis—acoustics, psychoacoustics, and vibrating media—are

analyzing his oeuvre, a complete list of spectral atoms can be realized. This list can be used as a reference to, then, start applying the atoms to canonic spectral works by composers such as Gérard Grisey.[123] The idea of gradually changing spectra, for instance, is a familiar concept to the composers of the spectral school.[124] Furthermore, Grisey uses this same atom in *Partiels* where, in the first section, he transforms the initial harmonic harmony into an inharmonic harmony gradually through each repetition of the spectrum.[125]

Although I am arguing to expand Lucier's music beyond the classification of minimalism, recognizing the minimalistic nature of his music can provide further insights to genre characteristics. The inherent spectral intentions of Lucier's music show each work of his *as a whole* to be a spectral process; that is, his music functions *as* a particular spectral process, not *because* of spectral processes. In theory, Lucier's pieces can be seen literally as spectral ideas in the

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effective; yet, there may be other ways to conceptualize spectral particles. In particular, I found myself combining room acoustics and tuning systems into one spectral particle. However, they may be better separated for application to other compositions. Instead of the current three spectral particles, they could be reorganized into four new spectral particles: space, organizational schemes, perception, and vibrating media. This amendment does not change any of the previous analyses, instead it serves as another way to understand his music.

[123] Not strictly limited to Grisey's music.

[124] The process of using mutes to filter the spectra in Grisey's *Modulations* mimics the overtone manipulation in Lucier's *Silver Streetcar for the Orchestra*.

[125] François-Xavier Féron, "Gérard Grisey : Premiére Section De Partiels (1975)," *Genesis* Vol. 31, (2010).

sense that someone wishing to write a canonic spectral work could sketch out a piece by combining the atoms found in his music.

The genre of spectralism could be recategorized with various subsets of spectral ideas to include Lucier's music. A categorization of spectral minimalism can house works such as *I am Sitting in a Room* because of its clearly repetitive process. A genre titled spectral experimentalism could include *Silver Streetcar for the Orchestra*, *Twonings*, and *Still and Moving Lines of Silence in Families of Hyperbolas*. In *Twonings*, Lucier explores the relationship between the different overtones of the cello against the piano.[126] A similar process can be said for *Silver Streetcar for the Performer*; the performer, in this case, is asked to explore the resonances of the triangle. Although the performance consists of repetitive striking of the triangle—like the repetitive nature of *I am Sitting in a Room*—the process of exploration places it further into the realm of spectral experimentalism.

Recalling the success of the qualitative study I described in the previous chapter, I would like to pursue the hypothesis that the presence of reverberation effects our perception of time. Already in the qualitative study, it was revealed that the presence of reverberation effects our perception of time, pitch, and

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[126] The sections of the piece contain clear patterns, but the patterns do not form an overarching pattern. Therefore, they each explore a unique pattern to reveal the tuning relationships.

speed. Therefore, to test how reverberation causes a change in all three of these perceptual areas, I am currently designing an experiment that will measure these responses in greater detail and with a larger participant pool.

In this experiment, I would like to present the subjects with four excerpt comparisons, each of which feature the exact same recording but varies in reverberation level. The four excerpts will be divided into two groups with two excerpts in each. The first group features repetitions on a non-pitched instrument and repetitions on a pitched instrument. This first pair will only contain steady repetitions that do not deviate in rhythmic complexity. The second group will feature the same non-pitched and pitched dyad but will incorporate rhythmic complexity that repeats on a loop. Of the two groups, group one's excerpt pair will feature the less-reverberant recording first, then the second excerpt will feature the more-reverberant recording first. The second group will be presented in the opposite manner. The participants will be split in two groups: the first group will hear the excerpts in the order described above, the second group will hear the opposite of this presentation order to pinpoint the results as an effect of reverberation, not memory.

Following each excerpt pair, the participants will answer a series of questions aimed towards how to manipulate the second excerpt to sound more like the first. Possible responses would include "make the first excerpt longer/shorter" or "raise/lower the pitch of the first excerpt." The first excerpt group will feature the same questions for both excerpts. A questionnaire between the excerpt groups will gather their demographic information. In addition to the questionnaire, the participants will be tested to see if they have perfect pitch. The perfect pitch test accomplishes two things: first, it distracts them from the previous excerpt group questions; second, if a student tests positive for perfect pitch, and their answers reflect that pitch changes with the presence of reverberation, it will further support my claim that reverberation skews perception.

In Closing

After defining the myriad of topics associated with sound, an understanding is made of the intentions in Lucier's compositional process. These topics separate nicely into three categories of sound, or spectral particles, and follow a sound production cycle: first a sound is produced through vibrating media, then the sound is altered because of the acoustics properties of the space in which the sound exists, and finally it is psychoacoustically perceived by a listener. These three spectral particles combine to form spectral atoms. By identifying the spectral atom, or atoms, present in Lucier's music, a better understanding can be made of the compositional intentions of the work and can then be better prepared for performance.

Lucier's music, grounded on the same phenomena and concepts made famous by the spectral movement, deserves analytical attention. His pieces usually focus on one phenomenon at a time: a spectral atom that is comprised of one or more spectral particles—acoustics, psychoacoustics, and vibrating media. On account of the minimal ideas pursued in his music, his pieces act as spectral études. Treating these pieces as studies, my analyses apply these concepts to Lucier's music to come to a conclusion about the main intention, or intentions, of the work. Analysis of this nature opens many doors to further analytical strategies regarding Lucier's music, as well as other composers, and their relationship to spectral ideologies. This thesis represents the beginning of my journey of uncovering the myriad of spectral atoms exploited in his music.

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Appendix

Focus Group Questionnaire

Name (optional)____________________ Years of experience in music____________

Degree____________________________ Instrument___________________________

Age_______ Email________________________________

I will be playing two musical excerpts for you. I would like you to critically listen to each of them keeping in mind ways you can talk about both the similarities and differences between them. Did anything catch your attention? Use the questions below to help verbalize your thoughts.

1. Have you heard this piece before? (circle) Yes No

2. Do you know who Alvin Lucier is? (circle) Yes No

3. Do you know what reverb is? (circle) Yes No

    a. If so, define it here.

4. What was your initial reaction to the music?

    a. Did your initial reaction change as the pieces went on? (circle) Yes No

    b. If so, how did your reaction change?

5. What were the biggest differences, if any, between the two recordings?

6. Describe the pitch content?

7. Was there anything interesting about the rhythm of the piece?

8. Describe the tempo(s) of the two excerpts.

    a. Was one faster or slower than the other?

    b. Did one fluctuate while the other stayed consistent?

9. Compare or contrast the lengths of the excerpts.

10. Describe the harmony, or lack thereof, in each excerpt.

11. Did you prefer one over the other? (circle) Yes No

    a. If so, why?

12. Do you have any other related thoughts to add regarding these two excerpts?

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EDUCATION

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2013 B.M. in Music Composition, *State University of New York at Fredonia.*

PRESENTATIONS

2018 "Beyond the Effect: The Perceptual Effects of Reverberation." The Fifteenth International Conference on Music Perception and Cognition and the tenth triennial conference of the European Society for the Cognitive Sciences of Music (ICMPC15-ESCOM10). Université Concordia: Montreal, Quebec, Canada (July 23–28).

2017 "Spectral Processes in the Music of Alvin Lucier." The Ninth European Music Analysis Conference (EuroMAC). University of Strasbourg: Strasbourg, France (July 1).

2017 “Repetition as Catalyst: The Process of Creation in the Music of Alvin Lucier.” EMC[2]: Remembering the Experimental Music Catalogue. De Montfort University: Leicester, England (March 25)

PUBLICATIONS

2017 “Reinterpreting the Role of Performer in the Music of Alvin Lucier.” *Journal of Experimental Music Studies.* http://www.experimentalmusic.co.uk/emc/Jems_files/bauschlucier.pdf

Forthcoming “Spectral Processes in the Music of Alvin Lucier.” In *Proceedings of the Ninth European Music Analysis Conference*. Edited by Pierre Couprie, Alexandre Freund-Lehmann, Xavier Hascher, and Nathalie Hérold.

TEACHING EXPERIENCE

2016– Music Theory Graduate Teaching Assistant at the University of Louisville.

- Instructor of two sections of MUS 091, Fundamentals of Music (Fall 2016).
- Instructor of one section of MUS 092, Fundamentals of Music II (Spring 2016).
- Instructor of one section of MUS 141, Music Theory I (Fall 2017).
- Instructor of one section of MUS 142, Music Theory II (Spring 2018).
- Technology assistance with online section of MUS 547/647, chromatic harmony, and MUS 548/648, post-tonal harmony.
- Substitute teaching.
- Theory and Keyboard Skill sessions.
- Theory tutoring.
- Grading for the theory department.

Spring 2016 Adjunct Instructor at the State University of New York (SUNY) at Fredonia.

- Instructor of one section of MUS 221, Aural Skills III.

- Material ranged from tonicization of closely related keys to chromatic modulation utilizing augmented and Neapolitan sixth chords.
- Responsible for training students to sing, dictate, and aurally comprehend these concepts.

▪ Proctor one-on-one exams testing students on fluency of selected melodic and rhythmic examples, intervals, scales, chord arpeggiations, and sight reading within the moveable *Do* and *ta-ka-di-mi* systems.

2013–2015 Teaching Assistant for the Music Theory department at SUNY Fredonia

▪ Instructor of one section of MUS 121, Aural Skills I (Spring 2014, Fall 2014, and Spring 2015).
  - Material ranged from establishing pitch class in a moveable *Do* system to note-to-note counterpoint.
  - Responsible for training students to sing, dictate, and aurally comprehend these concepts.

▪ Maintaining database of grades for all freshman and sophomore students.

▪ Proctoring audition placement exams.

▪ Proctoring exams.

WORK EXPERIENCE

2015–2016 Editor and media expert for *Musician's Guide to Aural Skills: Ear Training and Composition,* 3rd Edition.

▪ Correcting Roman numeral analyses using Finale.

▪ Creating rhythms and melodies for students to practice.

▪ Remastering of recorded examples for consistency.

2015 Cohen Studio Assistant at the Chautauqua Institute.

▪ Recording both audio and video for lectures and special events.

▪ Burning CDs and DVDs of lectures and special events.

▪ Pre-screening recordings and video for music students' applications.

2013–2016 Assistant House Manager for Rosch Recital Hall at SUNY Fredonia.

2010–2013 SUNY Fredonia School of Music computer lab proctor.

▪ Assisting students with computer, MIDI, and other technological issues.

- Maintaining the overall upkeep of the lab.

2011–2013 Student Assistant for the Music Theory Department at SUNY Fredonia.

- Grading papers for aural skills and music theory classes.

2009– Freelance recording engineer.

DISCOGRAPHY:

As a recording engineer:

2016 *Invisible Cities: American Music for Soprano Saxophone* (www.jacobswanson.com).

2015 "Broken Branch Rag," composed by John Bacon on *The NYFA Collection, Volume 2* (innova, 253).

As a composer

2017 "Mahogany," performed by Jacob Swanson on *Wired* (www.jacobswanson.com).

COMPUTING SKILLS

Music and Audio:

Finale, Logic Pro, Garage Band, Mainstage, OpenMusic, PureData (Pd), and The Composer's Desktop Project.

Graphics and General:

Photoshop, Microsoft Office, Keynote, iMovie, and Final Cut Pro.

AFFILIATIONS

Society for Music Perception and Cognition (SMPC).
Society for Music Theory (SMT).
Music Theory Midwest (MTMW).
American Society for Composers, Authors and Publishers (ASCAP).

SERVICE: *university*

2018 Summer Grant Review Committee

2010–2016 Ethos New Music Society Technology Chair.

- Live sound processing and recording of notable events and guests including: Roomful of Teeth, Third Coast Percussion, Akropolis Reed Quintet, Tony Arnold, Cornelius Dufallo, Chris Shultis, the Now Ensemble, Michael Mizrahi, Laura Koepke, the Baltimore-based Lunar Ensemble, Paola Prestini, Jeffrey Zeigler, Loadbang, the Colored Field Ensemble, Michael Lowenstern, Jamie Jordan, Modal Kombat, and the Mivos String Quartet, as well as various student recitals.

AWARDS

2018 University of Louisville's Dean's Citation Award
2017 Student Summer Travel Grant from University of Louisville.
2012 Ethos Laureate Prize in Composition for *Storm.*
2011 Poummit Concert Master Award.
2009 Donald Boland Scholarship Award in Composition.

RECENT COMPOSITIONS

2017 *Redwood* (Tree Suite) for bass trombone and electronics.
2017 *Mahogany* (Tree Suite) for soprano saxophone and tape.
2016 *Perception* for suspended cymbal and electronics.
2016 Tree Suite.

I. *Larch* for bassoon and live electronics.
II. *Wisteria* for flute and live electronics.
III. *Aspen* for violin and live electronics.

2015 *Perspective* for cello and live electronics.
2014 *Départ* for solo piano.
2013 Tri Suite.

I. *Prologue* for solo piano.
II. *Periods* for flute, violin, cello, double bass, percussion, and piano.
III. *Pendulum* for flute, clarinet, cello, double bass, percussion, and piano.
IV. *Chaos* for flute, clarinet, violin, cello, double bass, percussion, and piano

2013 *Ashes* for vibraphone, violin, cello, and double bass.
2012 *Storm* for double bass and live electronics.

PRIMARY PERCUSSION REPERTOIRE

Five Scenes from the Snow Country, Hans Werner Henze.
Liaisons, Roman Haubenstock-Ramati.
Six Japanese Gardens, movements I, II, and III, Kaija Saariaho.
Meditation No. 1, Casey Cangelosi.
Having Never Written a Note for Percussion, James Tenney.
Drumming: Part One, Steve Reich.
Silver Streetcar for the Orchestra, Alvin Lucier.
Still and Moving Lines of Silence in Families of Hyperbolas, ———.
Opera with Objects, ———.