SIMPLE SUBTLE SUSTAINED
WAVEFORMS AND THE NOTION
OF COMFORT IN A NEW
APPROACH TO CREATING AN
IMMERSIVE, INTERACTIVE
SOUND INSTALLATION

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ABSTRACT

This research considers compositional approaches to creating an immersive interactive sound-based installation. It explores the way sustained sine-tones set at subtle levels combine and propagate throughout a physical space, and how the notion of comfort can be used as a pretext for audience interaction. Research conducted as part of this study suggests that the notion of comfort in relation to sound is highly individualistic, and can lead to a variety of decision-making processes, such as where to stand, how to move through the space, how to negotiate the presence of others, how to engage and interact with the sonic environment, and in doing so, create a uniquely personal sonic experience.

These findings inform the creation and realization of a new interactive sound-art installation. Relationships range through the fundamentals of sound, perception of sound, conceptual approaches to sound art, and the particular phenomenological psychoacoustic aspects associated with the propagation of sine tones in physical space.

Discussion includes the philosophies, research design techniques, tools and methodologies used in creating the piece.

By Darren Steffen
DECLARATION

This is to certify that:

• ...The thesis comprises only my original work towards the masters except where indicated in the Preface,
• ...Due acknowledgement has been made in the text to all other material used,
• ...The thesis is 11,000 words in length, exclusive of tables, maps, bibliographies and appendices

Signed by the candidate:

Approved by:
Chairperson of Supervisory Committee:

Program Authorized to Offer Degree:

Date
LIST OF ACCOMPANYING MATERIALS AS DATA ON DVD

1. Electronic copy of this document - .pdf format

2. Sound Recordings:
   i. Research installation. Short excerpts of 5.1 surround sound recordings made (using a DPA 5.1 Surround sound microphone) to document the sonic content as presented to participants in the preliminary research phase detailed in Chapter III. Includes recordings of eight sine-tone combinations (Presets) as presented at each of the six nominated locations. See Table 1, page 23). Interlaced surround and multiple mono sound files included .wav format. Note: 5.1 surround sound capable software and playback equipment required to accurately audition these files.
   
   ii. Raw sine-tone sound files as used in research (Chapter III) and performance (Chapter IV), including 100Hz, 80Hz, 120Hz, 180Hz, 270Hz, 60Hz, 240Hz, 217Hz, 105Hz, 212Hz, 75Hz, 150Hz, 50Hz, 81Hz, 82Hz, 83Hz, 76Hz, 152Hz, 65Hz, 77Hz, 97Hz, 130Hz .aif format.

   iii. Performance stem output. Four stem bounces from performance presentation. Each stem is sent via a discrete output to a discrete loudspeaker as outlined in Chapter IV. Includes Stem 1: Output 1, Stem 2: Output 2, Stem 3: Output 3, and Stem 4: Output 4

See Appendix 2 (page 59) for a guide to recreating this composition using these accompanying materials, and other possible approaches.
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GLOSSARY

**Consonance:** From the Latin *com-*, “with” + *sonare*, “to sound”.

A concise definition of this term is elusive and the subject of much ongoing debate and discussion.

A general subjective definition may suggest a combination of tones that appears pleasant, or agreeable, to most people.

For the purpose of this dissertation, it may be useful to describe consonance as an individual perceptual auditory sensation where the combinations of tones are considered stable, or at rest.

“A stable tone combination is a consonance; consonances are points of arrival, rest, and resolution” (Kamien, 2008, p.41)

**Dissonance:** From the Latin *dis-*, “apart” + *sonare*, “to sound”

As with consonance, a general definition may suggest a combination of tones that sounds harsh, unpleasant, or disagreeable to most people. In musical terms, dissonance is often described as a temporary, transitional state toward consonant resolution.

For the purpose of this dissertation, it may be useful to describe dissonance as an individual perceptual auditory sensation where the combinations of tones are considered unstable, active, or restless. It is perceived as beating or roughness.

“An unstable tone combination is a dissonance; its tension demands an onward motion to a stable chord. Thus dissonant chords are ‘active’; traditionally they have been considered harsh and have expressed pain, grief, and conflict” (Kamien, 2008, p.41)
Perception: From the Latin *perceptio, percipio*,

Perception is “the organization, identification, and interpretation of sensory information in order to fabricate a mental representation through the process of transduction, which sensors in the body transform signals from the environment into encoded neural signals”. (Schacter 2011). This process of active cyclic neural activity takes physical stimuli and shapes it in relation to individual learning, memory and expectation.

Propagation: Any of the ways in which waves, including sound waves, travel and respond to physical displacement through processes such as absorption, reflection, diffraction and refraction.
INTRODUCTION

Comfort, like music, is difficult to define.

Edgard Varese described music as “organized sound” (Goldman, 1961), which implies a requisite subjective perception of sonic organization for music to exist. When applied more broadly to social constructs and subjective experience, music can be anything that is called music. For Berio, “music is everything that one listens to with the intention of listening to music” (Berio, Dalmonte & Varga, 1985, p.19). This perception could apply in any circumstance, and be available for any individual to apply idiosyncratically.

Comfort is equally unique to each individual and situation. The Oxford and other English dictionaries prefer to define comfort in physiologically terms as “a state of physical ease and freedom from pain or constraint” (“comfort”. Oxford Dictionaries. April 2010), thus avoiding the ambiguity of psychological characterizations; however, comfort can be described in terms of relief, happiness, contentment, pleasure, joy, gratification, fulfillment, or nothingness; that is, the absence of awareness. (Kolcaba, 2003; Miller, 2008).

Both music and comfort can be characterized as subjective phenomena. Both can be observed and experienced. Both are active, engaging experiences; however, precise connotations remain individually relevant, and are shaped by personal knowledge, background, perspective, understanding, awareness and enlightenment.

Past

Between 2000 and 2005, I participated in a series of concerts with instrumentalist Peter Barnes as the duo Fontana. The approach was to produce a single continuous tone that evolved and transformed slowly and subtly over a 70-minute time period. Inspired by Cage’s theory of Indeterminacy (Helms, 1993) and Grainger’s Free Music (after Busoni) (Balough, 1982), the piece evolved through subtly improvised manipulation of the continuous single tone using various electronic devices and techniques. Control of changes in pitch and amplitude were to be as gradual and as imperceptible as possible,
slowly becoming thick, rich and complex in texture, then receded gradually to return to the original unaccompanied single tone.

Anecdotal responses from the audience were varied, and ranged widely. Some people walked out during the performance, others experienced an escape response but stayed to engage the challenge, while some claimed to have entered a blissful trance-like state in which their temporal perception was suspended. It appeared that these sustained tone performances were capable of generating a wide and contrasting range of physical and emotional responses. Comfort for some, discomfort for others.

**Present**

This research explores this phenomenon in the context of a site-specific interactive sound installation. It raises the following fundamental questions:

- How can our awareness of comfort in response to perception of sound become an avenue through which to engage and explore a physical environment enhanced with subtle sustained sine-tones?
- How is our sense of comfort affected over time by subtle changes in pitch and amplitude relationships within a subtle sustained sine-tone environment?
- Are consonant combinations of subtle sustained sine-tones considered more comfortable than dissonant combinations?
- In a performative context, would this be of any interest to an audience, and why?

This dissertation addresses these questions by providing an account of the research conducted, and the application of findings to a methodology for creating a site-specific interactive sound installation. The following outlines the contents of each chapter:

- Chapter I introduces the notion of comfort in relation to sound, in particular, to the presence of subtle sustained sine-tones, and the particular propagation characteristics of these tones in a specific setting. I also discuss the specific technical, artistic and performative interest in sine-tones.
- Chapter II presents conceptual and theoretical foundations on which this work is based by way of a literature review, including the perception of sound, the act of listening, the ability to shape auditory experience, and the ever-evolving practices of conceptual art and phenomenology in relation to perception and interaction with sound art to create a physical performative space.
• Chapter III outlines preliminary research conducted as part of this study to explore the specific comfort reactions of individuals to subtle sustained sine-tone environments.

• Chapter IV describes the application of these findings in designing and presenting an immersive, interactive sound installation, where audience members become participants in the creative process by actively engaging with the sonic environment to shape individually unique experiences through subjective perceptual idiosyncratic filtering and decision making processes.

• Chapter V presents post-performance observations and overall findings.

The work has possible implications in a number of areas by: contributing a new method for developing sound designs, providing new information on how people interact with sound, providing composers with more information on sensory responses to certain tone combinations, and showing how sound can provide kinetic impetus as a spatial choreographic function, with possible relevance to those working in the growing areas of science of music, music perception, music therapy (Alsop & Steffen, 2009), and the emerging areas of performative architecture (Kolarevic & Malkawi, 2005, Jacucci & Wagner, 2005, and Macnaughtan, 2006).
CHAPTER I. THE NOTION OF COMFORT AS IT RELATES TO SOUND AND SINE-TONES

**Mapping comfort to sound**

Comfort may be considered a condition of life where needs are met (Kolcaba, 1995). The experience of need may range from vital to superficial, and depend upon situation and perspective. Life exists not simply in an environment, but through physical and emotional interaction with an environment. Dewey (1980/1934) considers unmet need as a lack of adequate adjustment; moreover, a demand to regain adequate adjustment, to a given environment. For Dewey, achieving adequate adjustment can be further enriched when resistance to this demand is met and overcome.

In relation to sound, we may tolerate the unpleasant effect of an intrusive sound by moving away or managing the imposition. This can be achieved in a number of ways: we can physically block our ears, and we can consciously and selectively filter our hearing by turning our listening attention elsewhere. According to Siever (2007), when we focus on something, we dissociate from other things. We can apply aesthetic considerations to transform the experience into something more satisfying. Leddy (2011, section 2.1, para 7) states that according to Dewey “life overcomes and transforms factors of opposition to achieve higher significance”.

**Sound and sensation**

Pitch is the perceptive incarnation of frequency. When presented simultaneously, certain pitch combinations may create agreeable (often considered consonant) and less agreeable (often considered dissonant) perceptual responses. Extremes of consonance and dissonance may parallel extremes in comfort and discomfort; however, variations in individual perception may undermine this assumption.

Pythagoras (582-507 BC) is credited with first articulating a perceptive relationship between agreeable pitch intervals and the frequency of movement in vibrating objects, noting that simple size ratios (2:1 and 3:2) between vibrating objects provided the most agreeable sounding pitch intervals (octave and fifth) (Rao, 2007). Although this
account is widely contested (Huffman, 2011), it is maintained that Pythagoras perceived these relationships while listening to tones emanating from the anvils of blacksmiths, and noticed that the more agreeable combinations of tone came from anvils that appeared to bear simple size ratios to each other (Riedweg, 2005). This observation demonstrates a process of active listening, a perceptual focus of auditory attention on a sonic event, in which frequency relationships are recognized.

While Pythagoreans concentrated mostly on the physical sonic properties of music, Aristoxenus, a pupil of Aristotle, argued in the 4th Century BC that one must understand the emotion that music elicits by looking into the mind of the listener. He advocated the establishment of music as a science unto itself with its own laws and principles based primarily in the context of sense, perception and memory rather than physics and mathematics (Barker, 1978). These proposals were contrary to the prevailing post-Pythagorean distrust in the evidence of our senses, and the “obsession with numerology” (Deutsch, 1980). Sense, perception and memory are key fundamental components of the listening experience, and take it beyond the process or mechanics of hearing to an individual emotional, aesthetic and psychological experience.

Hermann Helmholtz (1885) conducted the first significant controlled experiments on the sensation of tones and combinations of tones. He identified beating as the main contributor to the perception of roughness (dissonance) by the auditory system. Using a range of instruments including tuning forks and sirens, he determined that tones with fundamentals related to each other by simple ratios (unison 1:1, octave 2:1, fifth 3:2) share multiple frequency components, and when combined, produce little or no beating effect. Perceptually, this would appear pleasant (consonant) to the ear. Where two tones combined share fewer frequencies, beating is more pronounced and is perceived as roughness (dissonance) by the auditory system. 1

Worrall (n.d., para 4) explains Helmholtz’s principle as follows: “the whole-tone interval is more dissonant than the perfect 5th which in turn is more dissonant than the octave that is more dissonant than the unison, which presumably is more dissonant

1 More recent studies (Schellenberg & Trehub, 1994) show that very subjective judgments on sonic acceptability by musically trained and untrained subjects can be made when simple tones of relative ratio are presented.
than a single complex tone, which is more dissonant than a single sine tone - this being
the most consonant of sounds.”

I agree with this as a technical illustration of Helmholtz’s principle, although I question
whether a single sine-tone could perceptively be considered the most consonant, and
therefore the most agreeable or pleasurable of sounds. When situation and
environment are applied, the experience can change radically. Consider the slowly
rising single sustained sine tone that accompanies much of the 42-minute classic
Structural/Materialist film Wavelength (1967) directed by Michael Snow, where “the
synchronous natural street sounds are replaced by an electronic pitch, or sine wave,
which begins at a low 50 cycles and increases steadily to a shrill 12,000 cycles … this is
pure drama of confrontation” (Youngblood, 1970, p. 126-27.).

A single sine-tone may be experienced as confronting and difficult to endure, possibly
explained by the artificial and unnatural essence of a pure sine tone, and because of
this, may challenge the notion of consonance, pleasure and agreeability when
perceived.

The sine-tone

The production of a single smooth cosine waveform does not occur naturally. All
sounds in nature consist of complex sonic spectra; that is, contain a range of frequency
components with varying relationships to each other. This is due to many things,
including:

• The complex anatomical construction of physical matter that, when force is
  applied, vibrates and resonates in multipartite ways,

• The characteristics of sound propagation in a physical environment where
  reflection, refraction, absorption and diffraction create cancelations and
  distortions to further complicate sonic spectra.

Helmholtz (1885) created a mechanical siren for experiments in acoustics, and this is
considered the first device to produce a smooth cosine waveform. Electronic
oscillators, developed from the early 1900’s, are capable of producing pure sine waves.
The issue of purity is debatable due to distortion of the signal introduced by amplifier
and loudspeaker circuitry; however, with advances in circuit design, and we can now quite capably produce a perceptively pure sine-tone.

**Fourier**

The mathematician Jean-Baptiste Joseph Fourier’s theorem showed that complex sounds, including music and speech, can be deconstructed into sine-tone components, and these components bear integer multiple and simple ratio relationships to the fundamental frequency; for example, the upper components (harmonics or partials) of a tone with a fundamental of 100Hz would occur at 200Hz (2:1), 300Hz (3:2), 400Hz (4:3) and so on.²

This theorem explains that with each additional partial, the tone becomes more complex. Figures 1, 2 and 3 (below) show the accumulating effect of adding partials to the fundamental. Figure 1 shows a single sine tone at 100Hz. This is the fundamental. Figure 2 shows the fundamental plus the next partial, the first harmonic, at equal amplitude. Figure 3 shows the fundamental plus the first and second harmonic at equal amplitude. Notice how the waveform becomes more complex with the addition of each harmonic. Perceptively, with each additional harmonic, the sound would seem to transform and take on more-harmonically rich characteristics.

![Figure 1: 100Hz sine wave](image1)

![Figure 2: 100Hz with 200Hz sine waves combined at equal amplitude](image2)

![Figure 3: 100Hz, 200Hz and 300Hz sine waves combined at equal amplitude](image3)

*Source: Darren Steffen*

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² See Maor (2002) for a detailed account of Fourier’s theorem. It is worth noting that this theorem was designed as a system for integrating data, and not specifically in relation to audio.
To further illustrate the increasing complexity of accumulating sinusoidal partials, Figure 4 (below) shows the superposition of sine waves up to the fifth harmonic above the fundamental to create a complex compound sawtooth wave.

“Superposition of sinusoidal wave basis functions (bottom) to form a sawtooth wave (top); the basis functions have wavelengths $\lambda/n$ (n=integer) shorter than the wavelength $\lambda$ of the sawtooth itself (except for n=1). All basis functions have nodes at the nodes of the sawtooth, but all but the fundamental have additional nodes”. (Ohare, 2009)

Figure 4: Superposition of Fourier components of a saw-tooth wave. Ohare, 2009.

Fourier analysis is an effective method for identifying the individual frequency and amplitude components of complex sounds, and is useful in describing the way sound components are affected by processes such as propagation and filtering, by providing before and after spectrum analysis. In *Signals, Sound, and Sensation* Hartmann (1997) uses the Fourier transform theory to unify topics as diverse as cochlear filtering and digital recording. Combining sine-tone components is used in FM synthesis to create perceptually recognizable synthesized versions of musical instruments such as clarinet and trumpet (see Chowning, 1973). Sine-wave speech uses multiple sine tones (surprisingly as few as three) to replicate the sweeping formant characteristics of speech.³

**Performative interest in sine-tones**

The primary performative interest concerns the nature of interaction with a physical environment subtly enhanced with sustained sine-tones, and how the notion of

³ For more on sine-wave speech, see www.haskins.yale.edu
comfort can be used to guide this interaction while perceiving the unique, possibly unfamiliar, perhaps even disconcerting propagation behavior of sine-tones.

Due to their simple sonic nature, sine-tones are controllable and accurate stimuli with which to test, measure and analyze physiological and psychological ability and perception (Weiner et al. 2003, pp. 72-99). These cases restrict the testing environment to headphones. Once in the open air, sine-tones become subject to the rules of propagation. Under these conditions, sine-tones display unique acoustic characteristics, and are implicit in a number of distinctive auditory illusions. These distinctive characteristics are outlined below.

1. The Fransen effect
Sine-tones are remarkably difficult to localize. This is clearly illustrated by the Franssen effect (Blauert & Allen, 1997). This effect uses two loudspeakers - Loudspeaker A (LSA) and Loudspeaker B (LSB) - set apart in a room, and shows that once the origin of a fixed sine-tone is presented (usually indicated) and perceived to originate from LSA, that perception is maintained, even when the tone pans from LSA to LSB. In some cases, this perception is maintained even when LSA is disconnected. This illusion clearly illustrates the difficulty our auditory perception has when localizing with sine-tones.

My interest is in the clear perceptual separation this creates between the sound source and the sound object. This removes causal associations with a source, and allows the person to accept the sound for what it is, at that moment, and in that place.

2. Phase Interference
Also of interest, is phase interference effects perceived when sine-tones coincide acoustically (Ballou, 2002, p.13). Their relatively simple waveform structure promotes this pronunciation, and the effect of both constructive (promoting) and destructive (cancelling) interference is remarkably apparent. Figure 5 (on the following page) shows these effects as applied to sine waves. As sine-tones propagate, reflect and coincide throughout acoustic space, broad fluctuations in amplitude occur, from doubling (constructive) to cancelling (destructive), the later creating points at which the tones seems to disappear.
Wave 1
Wave 2
Combined
Waveforms

Constructive interference
Destructive Interference

Figure 5: Phase Interference. Source: Darren Steffen

3. Beating, masking and Critical Band

Beating is the interference between two tones of very similar, but not exact, frequencies. At exact frequencies, the two tones sound as one. An example is using harmonics to tune a guitar. Tuning between two strings is achieved when the two harmonics sound as one. If the two tones are slightly apart in pitch, interference occurs, and the constructive and destructive fluctuations create rapid and pronounced changes in amplitude. This excites the ear mechanism in a way that is perceived by most as unpleasant (Hall & Hess, 1984). As with phase interference, this is more pronounced with sine-tones due to the relative simplicity of the waveform.

Masking is the reduced audibility of a sound signal when in the presence of a second signal of higher intensity and in very close frequency proximity.

Fletcher (1940) identified critical bands as a range of frequencies either side of a fundamental in which beating and masking occur. When the critical bands of two tones are adjacent, the resultant beating within the critical band is perceived as dissonant or unpleasant. Outside of the critical band, these interferences are reduced, and the tones are perceived clearly as separate aural entities. Plomp & Levelt (1965) mapped the relative consonance and dissonance of critical bands as shown in Figure 6 on the following page.
“The effect of combining two tones. Unison (Point #1) creates 100% consonance. A separation of one whole critical bandwidth or more is required for a return to 100% consonance. If the two frequencies are separated by less than one whole critical band, varying degrees of dissonance is heard. The most dissonant combination of two tones is at around 0.25 of a full critical bandwidth”. (Plomp & Levelt, 1965)

Figure 6: Critical bandwidth consonance mapping (Plomp & Levelt, 1965)

The three key acoustic phenomena outlined above can lead to dynamic shifts and variations in perceived tone quality and intensity within an acoustic space, even when the sonic content presented is constant and stable. As suggested above, these effects are made obvious using sine-tones. The specific tone combinations present would determine the degree of variation within the space. Individual positioning, movement, aural awareness and depth of listening ability would determine the perception of these variations. These factors form a large proportion of the discussion in the following chapter; inform the research outlined in Chapter III and figure prominently in the development of the compositional approach presented in Chapter IV.

For a discussion on other composers and compositions that employ sustained tone textures – in particular sustained sine-tones textures - as a key compositional device, please see Appendix 1, page 55.
CHAPTER II. LITERATURE REVIEW

This chapter will correlate discussions on the perception of sound, the act of listening, the ability to shape auditory experience and the application of conceptual and theoretical approaches to considering auditory experience as art.

Hearing and Listening

“Of silence, paradoxically, one can only speak” (Tacussel, 1988, abstract).

Our acoustic world is full of multi-layered, dynamic, complex sound. Unlike our eyes, our ears have no lids. Even in the fabricated zero sound emission and reflection environment of an anechoic chamber, our internal bodily functions such as heartbeat, blood flow and digestive activity become audible. (Blesser & Salter, 2007, p. 18). It is therefore impossible for individuals with normal auditory capability to experience total silence. We are constantly exposed to sound.

Even so, it is broadly claimed that the predominant sense in western societies is visual (Pocock, 1981; Levin, 1993). This has not always been the case. Western society has been transformed from a predominantly aural to a predominantly visual culture through technological revolutions such as the printing press and the personal computer (Classen, 1993; Crosby, 1998). In the context of human evolution, this is a very recent shift, and it would be incorrect to assume that human auditory capacity, as developed over millions of years as a primary communication and survival device, is now less effectual.

It would also be incorrect to assume that senses operate in isolation, or accord to a particular hierarchical model. Higher-order multi-modal cortical responses contain cross-modal associations between sensory systems (Binder et al, 2004). Extensive research has reliably identified a systematic relation between hue and pitch (Simpson, Quinn & Ausubel, 1956), and brightness and loudness (Stevens & Marks, 1965; Root & Ross, 1965; Marks & Stevens, 1966).
Auditory Objects

Given this integral interconnectedness between senses, according to Jonas (1954), ancient Greek philosophers suspiciously regarded the temporal and fleeting ephemera of hearing as a less noble sense than the simultaneous and fixed essence of sight. Jonas relates the Greek visual bias to the formation of the concept of objectivity, in that sight allows the observer to avoid direct engagement with the object of his gaze, or “the thing as it is in itself, as distinct from the thing as it affects me” (Jonas, 1954 p. 147). This assertion denies the intrinsic link between subject and object, in that observations are experientially conditional to individualistic precedents. Nagel (1986) eloquently illustrates this by explaining that objective reality is inherently conjoined to oneself, and the perceptual disposition of the mind at a given moment.

The Oxford English Dictionary defines an object as “a material thing that can be seen and touched” (“object” Oxford Dictionaries, April 2010). Not only does this definition ignore taste, smell and hearing, it implies that as a material thing, an object is distinct from the sensory world to which it is presented. Not only must objects be considered the domain of all senses, but that they also exist within the sensory domain as “perceptual entities that depend on the brain mechanisms available to represent and analyze sensory information” (Griffiths & Warren, 2004, para. 3). This maintains that the concepts of an object, and of object analysis, can be regarded as inseparable. Neuroscientists increasingly refer to auditory objects as perceptual representations of sound (Kubovy & Van Valkenburg, 2001), although a clear definition of what precisely constitutes an auditory object is still emerging (Griffiths & Warren, 2004).

Auditory Scene Analysis

Perceptively, an auditory object may be considered an individual sound, a collection of sounds, or all sounds as heard simultaneously within an environment. Sounds can temporally appear instantaneous or continuous. Bregman (1990) describes sounds as streams, which can be perceived individually, as groupings, or collectively within an overall aural scene. This he termed Auditory Scene Analysis. This ability is common but variable, relying on an inbuilt ability to listen actively and engage with the sound world. When listening to an orchestra, or recording of an orchestra, individuals are capable but not always conscious of their innate ability to determinatively shift perception from the entire orchestral scene, to focus on a grouping of instruments such as the woodwinds, or to follow an individual melody of a single instrument such
as the clarinet. More highly skilled listeners may focus on the reverberant characteristics of the room. Others may notice coughing in the audience, birds outside the concert hall, or some low-frequency mechanical component caused by air-conditioning or traffic. This may be dexterous in some, less in others, but inbuilt in all as a residual skill which enabled our ancestors to locate prey or avoid predators otherwise unseen. An ability to associate meaning and predict consequence is an important part of higher-level auditory analysis.

Griffiths & Warren (2004) proposed a framework that comprehensively lists existing models of “auditory object analysis”, including Bregman’s streaming input model, and maps these from sound input to behavior outcomes (see Figure 7, on the following page). At the input is basic encoding at the Cochlea. The second stage identifies auditory features by modulation and spectrotemporal detection in the ascending auditory pathways to the primary auditory cortex. Abstraction by invariance computation and sensory memory in the ‘computational hub’ of the auditory cortex constitutes the third stage, followed by cross-modal analysis in the multi-modal cortex, and schema analysis through object categorization in the Higher Cortices. The model allows the possibility of bi-directional processing between the three latter stages through a looping re-referential process.
Figure 7: A Framework for models of auditory object analysis (Griffiths & Warren, 2004, p. 890). This figure lists the models discussed by Griffiths & Warren as “a hierarchy of operational processing stages” (left) and offers “neuroanatomical substrates for these operations” (right). “The putative flow of auditory information is indicated (red arrows); the exchange of information with higher order cortices and other sensory modalities is probably reciprocal (bi-directional arrows). The precise order of processing stages (for example, cross-modal analysis and schema analysis) probably depends on task demands. AIM, auditory-image model; PAC, primary auditory cortex” (Griffiths & Warren, 2004, p. 890).

This framework clearly shows that the perception of auditory objects is a specifically experiential cross-modal and continuously referential occurrence, and illustrates a process that takes the representation of an auditory object far beyond the simple perceptual registration of hearing to a rich, active, conditional and experiential act of listening.

Acousmatics, the Pythagorean veil and phenomenology

Pierre Schaeffer, a main exponent of Musique Concrète, coined the term Acousmatics (Schaeffer, 1966), a concept that derives from a Pythagorean practice whereby disciples would listen to Pythagoras teaching from behind a veil, thus allowing the listener to focus on words and meaning without the distraction of concerns for a causal relationship. Schaeffer points out that this is the way in which modern technology separates the source of the sound from the listener. For Schaeffer, it was the experiential presentation and combinations of the sounds themselves that was important, rather than the causal relationship to a particular situational origin.
Kane (2008) however offers alternative accounts that suggest the Pythagorean veil was a *figurative* device that separated disciples with heightened ability to understand their master (inside the veil), from others with limited or early development of understanding (on the outside). This figurative positioning provides a tantalizingly metaphorical allegory between hearing and listening, between listening and understanding, about being in touch with our auditory sense, being conscious of the depth of effect, and empowering the listener to actively shape their experience.

Whether a true account or convenient myth, the Pythagorean veil promotes a focus on the auditory object, as it exists, removed or separated from a visual and causal connection.

Acousmatics is encapsulated in the thinking of philosopher Edmund Husserl (1907) and the concept of phenomenology, where human contribution is an inseparable part of the subject matter. In *Music as Heard*, Thomas Clifton (1983) applies phenomenological understanding to a definition of music. For Clifton, music is “an ordered arrangement of sounds and silences whose meaning is presentative rather than denotative” (p. 1), and music is *not* “an autonomous appearance, but the outcome of a collaboration between a person and real or imagined sounds” (p. 74) where a person is doing more than just listening, “he is perceiving, interpreting, judging, and feeling”, and in doing so, “experiences musical significance by means of, or through, the sounds” (p. 2).

Phenomenology is therefore key to understanding the perception of an auditory object not only separated from a causal relationship, but in a performative interactive context of distinct individual perception and analysis - as it is, where it is, and when it is – as an accumulating dynamic coincidental mind-body encounter.

**Reduced listening**

Schaeffer also coined the term ‘reduced listening’, a sophisticated listening mode that focuses on the traits of the sound itself, independent of its cause and of its meaning. Considering the auditory scene, the listener listens without attaching learned responses or habitual references. Chion (1994) included reduced listening in his three-mode model, along with Causal (everyday) and Semantic (context-related, codified, language
oriented) listening. For Tuuri et al. (2007, p. 16), “the sound phenomena itself requires that a listener is consciously resisting any denotations of a sound source or its meaning. This mode of listening is thus exceptionally voluntary and very likely requires high-level cognitive abstraction.”

Similarly, part of the aim of John Cage’s aesthetic of indeterminacy (Kostelanetz, 1993) as developed in the late 1950’s, encourages a non-judgmental Zen-inspired approach to listening where the audience is asked to listen openly and without judgment in order to obtain a state of mind in which they become aware of the physiological and psychological effects of the sound, rather than making judgments and comparisons about the musical profile or attributes such as musical character, performance source, compositional intent, melodic or harmonic balances, and musical form.

Pauline Oliveros offers one of the most appealing post-Cage extensions of this thinking in her theory of Deep Listening (Osborne, 2000). Deep Listening focuses on “the auditory environment and the processes of cognition that shape our perception of it” (Osborne, 2000, para 21). Through the series of compositions entitled Sonic Meditations, Oliveros developed Deep Listening as an egalitarian approach to creative listening and performance that evaporates preconceived western notions of composer, conductor, performer and audience. These works are designed for anyone to participate regardless of music training. They are largely improvised according to notated directions to the performers. For instance, the score for Sonic Meditation X (Oliveros, 1974), consists of the following direction:

“Sit in a circle with your eyes closed. Begin by observing your own breathing. Gradually form a mental image of one person who is sitting in the circle. Sing a long tone to that person. Then sing the pitch that person is singing. Change your mental image to another person and repeat until you have contacted every person in the circle one or more times.”

This direction offers participants a guide to exploring deep internal personal and interpersonal emotional, philosophical and psychological states through their engagement with sound in an immersive, interactive way not possible in the context of passive audience associations typical of traditional western concert performance.
Aural connection with environment and surroundings

Deep aural engagement with the environment is also the basis of Soundwalking. A sound walk is “an excursion whose main purpose is listening to the environment” (Westerkamp 1974 p. 18-19). In the soundwalks of Westerkamp, each participant is encouraged to engage and develop a unique aural connection with a physical environment. To assist in establishing this connection, written material is provided at the onset to inform, inspire, and influence an initial interaction, thus providing a mechanism for focusing aural attention. The written material may vary in length and specificity, and be designed to support a particular artistic intent. Given this impetus, participants proceed to engage with the aural landscape, as it exists, in and of that moment, in a direction and to a depth of listening chosen by each individual. This example shows effective use of initial guidance and suggestion as an introduction to an aural environment, a key part of the research and composition process discussed in the following chapters.

Minimalist music, Conceptual Art and Post-dramatic Theatre

The minimalist movement in music evolved in response to the European modernist musical traditions that employed complex serial and post-tonal structures. Similar responses evolved in visual art and architecture where the design focus was on the reduction to essential qualities such as light, form, space, place and human condition (Bertoni 2002). Conceptual Art is more concerned with the idea behind the work, the process, and the effect that has upon the audience - art as experience rather than as a static object. Works of conceptual art are designed to make you think (Schellekens, 2009). Post-dramatic theatre reduces the text and elevates other elements such as light, sound and space as fundamental to the experiential exchange between artist and audience (Lehmann, 2006). Conceptual art and post-dramatic theatre similarly focuses on reducing components to essential experiential effects.

The influence of these artistic movements can be seen in the essential experiential effects contained in contemporary technological-based art, virtual art and new media art developed since the 1980’s. Popper (2007) maintains that new media art brings “its humanization of technology, its emphasis on interactivity, its philosophical
investigation of the real and the virtual, and its multisensory nature” (MIT Press online catalog, 2012). For Popper, the extra-artistic goals of new media artists, “linked to their aesthetic intentions, concern not only science and society, but also basic human needs and drives”. (Boden, 2006, p. 1089).

In considering these artistic movements and concepts, it is the effect the work has upon the audience that is of interest. Here the line between artist, composer, performer and audience blurs when immersion in an elemental interactive process becomes the primary mode of engagement. This removes prescribed denotation and recommissions and elevates the traditional passive-observational-receptive audience archetype to the realm of key creative. The artist may set the provision of circumstance, yet the final realization is dependant on individual multisensory interaction, engagement, response, and reflection.

**Conceptual interconnectedness**

In Chapter I, I identified and discussed notions of comfort, sine tone characteristics, and performative interests. In Chapter II, I have reviewed and discussed the individualistic experiential and phenomenological perspective of listening, which is rendered according to substratum sensual, socio-cultural, personal creative and dynamic behavioral dispositions of each individual. However, processes of combining and interconnecting these areas in the creation of a temporal sound-based artwork have not previously been discussed in the literature.
CHAPTER III. PRELIMINARY RESEARCH

This chapter outlines research conducted to investigate and collect data on responses to subtle sustained sine-tone environments when considering notions of comfort.

In brief, a number of sine-tone combinations were presented to participants in an acoustic space. Participants were asked to consider their comfort level at numbered points around the space, and on exiting, nominate where they felt most comfortable by placing a counter in a correspondingly marked cup.

The following outlines the approach, methodology and findings of this research.

Comfort as indicator

In determining responses to stimuli, researchers often rely on physiological indicators such as changes in body temperature and heartbeat. This usually requires the attachment of measuring devices and is not conducive to freedom of movement. Psychological indicators require no such attachment and provide free movement; however, the compromise is a decrease in scientific accuracy.

This compromise was not only considered acceptable, but essential, given the interest in the questions relating to the self-determined assessments of comfort, demanding the collection of data based on individualistic conditional perceptual responses. Comfort is a psychological state that individuals can monitor and consider individually. It can take in a number of factors including physical and emotional states. Depending on the individual, it could refer to a range of emotional responses including calmness, consolation, relief, cosiness, wellbeing, solace, succour, relaxation, contentment, satisfaction, reassurance or security, as discussed in Chapter I.

Developing sound content

Software generated sine-tones were a chosen as the sound source. They offer:

- Accurate and reliable generation, control and monitoring of sine-tones,
- Variations in signal routing,
- Ease-of-use in fine-tuning, storing and recalling tonal configurations
Pitch

Figure 8 (below) is a screen shot of the custom software patch written for this process. The cycle~ object provides a default cosine with variable frequency. The level is set using the slider or number box attached. The patch presets store specific configurations of component values. For instance, Patch Preset 1, as shown in Figure 8 below, would generate four sine-tones at 100Hz. Notice each tone is mapped to a unique output. Each discrete channel output is patched to a discrete speaker in the space.

Figure 8: Software patch (Max/MSP) used for sine-tone generation.

Figure 8 above shows Patch Preset 1 - the calibration patch used to test the speaker set-up. As shown in Table 1 on the following page, the actual tonal combinations used as stimuli ranged in frequency 50Hz to 270Hz. This is relatively low in the frequency range of human hearing, and was specifically chosen as:

- Low frequency sine-tones are difficult to localise, enhancing the separation between sound object and source
- Low frequency tones introduce physical mechanical transmissions, creating physical as well as aural stimulus
• Low frequency wavelengths are physically long in dimension, and this creates distinct and easily perceived areas of positive and negative convergence within a space, compared with much higher (shorter) waveforms.
• Mid and high-pitched sine-tones were avoided as they may invite stronger negative associations established in previous experiences.

The table below lists the nine tonal presets used.

Table 1: Preliminary Research: Preset frequency values and mapped outputs used for data-gathering

<table>
<thead>
<tr>
<th>Preset</th>
<th>Output (Channel) (f Hz)</th>
<th>Notes</th>
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</thead>
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<tr>
<td></td>
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<td>Ch 2</td>
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<td>1</td>
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<td>150</td>
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<tr>
<td>9</td>
<td>65</td>
<td>77</td>
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</tbody>
</table>

Some presets were specifically designed to contain consonant relationships, using simple ratio relationships. Some states were designed to be dissonant with tones set to close frequencies to ensure resultant beating.

The mixture of consonant and dissonant states was designed to test comfort responses at different locations in the room. In some cases, phase cancellation and comb filtering created places where dissonant roughness and beating was less pronounced, and it was expected that these locations would register greatest comfort, or least discomfort, when these dissonant states were in effect.
Amplitude

Subtle sound levels were chosen as:

- Sine-tones at mid to high pressure levels may appear very overwhelming and uncomfortable
- At just noticeable amplitude levels, the tones may subtly influence rather than dominate the space
- Low levels may require and encourage deeper listening
- Low levels may assist in long term engagement with the installation

The amplitude for each speaker was set so that the experience of the amplitude was subjectively similar – no objective measuring devices were used.

Venue Layout

The venue chosen was Gallery B, Northern Melbourne Institute of TAFE (NMIT), Fairfield campus. It was chosen for convenience to author’s workplace, and high level of exclusive use and control throughout the research period. The placement of the speakers was considered in relation to two main issues: the proximity of speakers to participants, and the proximity of speakers to venues corners. Too close to participants, and anxiety levels may rise. Too close to corners, and overstated standing waves and low frequency resonance at certain frequencies would result. The final placement was a compromise where the speakers perceptively felt comfortably distant without producing noticeably over-pronounced resonances. Figure 9 (on next page) shows a view of the gallery facing west with two of four speakers positioned at the end of the room. Two more were placed in similar positions at the other end of the room (immediately behind the photographer).
Figure 9: View of Gallery B looking west, showing listening six positions, two of the four speakers, and the computer desk and audio interface table at the end of the room. The signs against the wall say “please-look-this-way” which helped to ensure all participants faced the same way.

The dimensions of the Gallery B space are shown in Figure 10 on the next page.
Figure 10: Gallery B layout including speaker placement (1-4) and listening locations (1-6)
Research Procedure

On arrival, participants were provided with information describing the project and instructions on how to participate.

Each preset state (as listed in Table 1, page 23) was presented for a three hours period over the course of four days. Participants could attend and engage once with each state during that time.

Participants were asked to stand at a series of six numbered positions and to consider their state of comfort at each⁴. Once each position had been assessed for comfort level, participants were asked to consider at which location they felt most comfortable. Each participant would then place a marble into the cup marked with the number that corresponded to the position at which they felt most comfortable.

Participants were not provided with a description of the term comfort. They were asked to consider their own meaning, and to reflect on this as they stood at each location.

Anecdotal responses provided voluntarily by some participants suggested that comfort often translates as stillness, calmness, or tranquillity. For these participants, it would be reasonable to say that the place of greatest comfort was the position that offered the least sonic oscillation (beating caused by close frequency proximities between tones), and the place of reduced amplitude (caused by phase cancellation). One participant suggested that there were positions in the room other than those marked that they found more comfortable, in particular, in the direct centre of the room, which for most presets would have been the place providing greatest phase cancellation due to the position of the speakers. Another participant suggested that no place in the room felt completely comfortable, but in the context of the directions, voted for the location that provided the least discomfort.

⁴ see A4 paper sheets on the floor in Figure 9
The internal environment of Gallery B contained significant background noise from the climate control system. Position 3 in particular was directly below an air conditioning outlet that was operating during all sessions.

**Research Data**

Table 2 below represents the data from two perspectives – most and least preferred position by Preset, and most and least preferred position by Position.

Table 2: Preliminary Research: Most and least preferred by Preset. This maps the response recorded per preset. The table is laid out in a way that represents the physical orientation of the venue, with the four loudspeaker positions (LS) and the north wall marked in each. The frequency (Hz) and relative level (dB) for each speaker is listed. NB: preset 1 used for testing purposes only and not used to collect data, therefore not shown here

√ = Most preferred BY PRESET
X = Least preferred BY PRESET

LS = Loudspeaker

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<th>Preset 2</th>
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Table 3: Preliminary Research: Most and least preferred by Position. This maps the positions that attracted the most and the least votes across all presets. Position 2 and 5 were clearly most preferred. Positions 4, 6 and 3 least preferred. NB: preset 1 used for testing purposed only and not used to collect data, therefore not shown here.

<table>
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<th>Position</th>
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<th>5</th>
<th>6</th>
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<td>4</td>
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<td>5</td>
<td>X</td>
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<td>X</td>
</tr>
<tr>
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<td>5</td>
<td>X</td>
<td>1</td>
<td>X</td>
<td>1</td>
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<td>X</td>
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<td>22</td>
<td>15</td>
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<td>X</td>
<td>25</td>
</tr>
</tbody>
</table>

Most preferred BY POSITION

Least preferred BY POSITION

Research Findings

It was found that regardless of the specific sonic state present at the time of engagement, certain places were identified in favour of other as being the preferred place of comfort. From the research conducted, the following points can be made:

- Simple sinusoidal waveforms do propagate and combine within a room to create varying sonic relationships that change depending on the location in the room.
- Levels of comfort can vary at different positions in a room depending on the tonal combinations present at each location.
- Some positions were more conducive to providing a more acute sense of comfort. These positions tended to be places of greatest phase cancellation (reduced presence of tones) and reduced beating (less dissonance/roughness).
- Some positions were more conducive to providing a more acute sense of discomfort. These tended to be places where the combination of speaker location and sound propagation led to increase sound intensity, and more pronounced beating effects.
There is a clear suggestion that specific sonic environments can influence the proximity location preferences of participants in response to a comfort seeking direction.

Given directions, individuals can listen to the sonic component of a room at a deep engaging and interactive level.

Anecdotal reports suggested a high level of interest in the concept and willingness to engage with the process.

The results should not be considered as a reliable way of universally predicting the effect of specific frequency combinations, as the testing is entirely dependent on the room in which the testing took place, and the specific propagations that occurred in that room. They are also influenced by a low participation rate.

However, the results provide enough material and experiential evidence to inform an approach to composing and designing a site-specific interactive sound installation. This process is described and discussed in the following chapter.

A series of short 5.1 surround sound recordings were made of each of the locations, and these appear as part of the audio materials accompanying this dissertation.
CHAPTER IV. COMPOSITION METHODOLOGY

This chapter describes the design and presentation of an immersive, interactive sound installation, where audience members become participants in the creative process by actively engaging with the sonic environment to shape individually unique experiences through subjective perceptual idiosyncratic filtering and decision-making processes.

From the findings described previously, the following precedents were established as guiding considerations in creating this new work:

- Sound propagates inconsistently throughout a room
- Sine-tones are unnatural and can create a range of psychoacoustic illusions and anomalies including displacement and disconnection with sound origin
- Sustained tones can affect emotional states and distort temporal senses
- The human auditory system can focus on components of an auditory scene
- Sound can have a strong impact on the emotional state
- Simple, subtle, sustained tonal states allow participants to engage with the sonic environment on an intimate and personal level
- Individuals have developed life-experience in considering the impact sounds have on their state of comfort and wellbeing, and this is highly individualistic
- Given appropriate guidance, an audience can apply deep listening techniques to engage willingly and actively with an aural landscape

With these guiding considerations in mind, I established a compositional and presentation process, which involved:

- Choosing the tonal and temporal parameters
- Constructing the piece
- Determining and arranging production requirements such as venue, sound and lighting logistics
Tonal

The nine tonal presets used in the data-gathering phase (Chapter III, page 23) remained the preferred choice of the tonal palette for composition as they provided a mix of dissonant and consonant relationships, and their use throughout the research stage had developed a level of familiarity and understanding I was comfortable with.

Temporal

Many choices for temporal design are available. Shape and structure could be borrowed from any number of musical traditions. For example, musical structures such as sonata form to a contemporary jazz standard could dictate the temporal realm. In this case, I felt it important to pursue a simple minimalist aesthetic by establishing a simple, repetitious internal rhythm to the composition. Slow, smooth changes at equal points in time offers regularity, predictability and familiarity, essential conditions for individuals to focus on internal personal responses to the sonic environment without the anticipation of sudden change or surprise. This aesthetic follows the temporal objectives applied in the performances of Fontana outlined in the Introduction. As applied to this composition, the sustained states with long, slow transitions allow participants to fully investigate each tonal state, to find their preferred place of comfort, to observe changes to each state, and to investigate the entire space fully (if required) to compare other places for sense of comfort. To achieve this, I nominated a total duration of 4 minutes per preset. This included the following amplitude envelope:

- 0-1-min. = fade in
- 1-3-min. = sustain
- 3-4-min. = fade out

This envelope is illustrated in Figure 11, below.

Figure 11: Amplitude envelope

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Amplitude (relative to each preset)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<tr>
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<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Constructing the piece

Pre-composed content

Figure 12 graphically represents the time line established for the piece, with each preset state appearing as a 4-minute region (in grey). This blocked timeline, or “score”, illustrates the regularity of the temporal design described above. It shows the duration of each preset, and the cross-fade regions. It also lists the frequencies used in each preset at each output. During cross-fade regions, the tone from the previous state cross-fades with the tone from the next state in a direct linear relationship as illustrated by the fade directions. Two tones emit from each speaker during cross-fades. Between cross-fades, only one tone emits from each speaker.

The work could be constructed using a number of different software titles, as the majority of contemporary programs contain sine tone generators as virtual instruments. In this case, the tones used in the data-gathering process were exported from Max/MSP as audio recordings, and imported into Logic Pro for easy manipulation and arranging.

It would be possible to realise this as a generative synthesis piece by programming temporal events in Max/MSP, or other software, and this remains a possible future endeavour.

---

5 This amplitude envelope is applied to all but the first state, the establishing state, which sounds unaccompanied for two minutes on introduction, being equivalent to the second and third minutes of the proceeding states where the presets sound without crossing to, or from, other presets. This is illustrated in Figure 12
Conceptual content

This piece requires more than just the pre-produced sonic content. To exist as intended, it needs a physical space and audience participation.

The following elements and conditions are essential:

• Pre-composed sound elements matching the tonal and temporal structures outlined above

• A room, preferably empty, somewhat reverberant, and free from obstructions that might limit audience movement.

• Appropriate lighting to allow quiet contemplation and safe movement

• Sound equipment required to present the pre-composed sound elements

• A participating audience

• An external room or antechamber where an audience can receive instructions prior to entering

The following is an extract from notes written at the beginning of the design process, and illustrates the conceptual premise:

In brief, people attending the performance will not engage with the work in a traditional seated situation common to western performance settings. They will be asked to stand and move around a space and listen deeply to the sound in – and of – the space, and to respond to the sounds they bear in considering their own sense of comfort and being. They are asked to seek a place that offers the greatest sense of comfort – whatever that may be for each person. Once that place is discovered, stay there until it’s no longer comfortable, and then move around the space until comfort is regained. They continue doing this for the duration of the performance. A definition of comfort is not provided, and the audience is free to interpret, or even ignore this directive if it makes them feel more comfortable! The audience creates the performance. There are macro and micro scales of performance – that which the individual is experiencing internally, and that which is created by participants moving around a space. Both are affected by the social, political, cultural and personal sensitivities each person brings to the space in terms of their aural sensitivities, proximity to strangers, and willingness to engage. The participants create a visual form through movement - an improvised sonic choreography - that will be unique unto each performance, whether it is a group performance, a solo
The experience of the piece is in performance, which can only be achieved through audience participation in a physical space. It is inappropriate for this piece to be documented as a video or audio recording as no technology currently exists that could accurately capture the interactive experience. To do so would misrepresent the piece as it can only be experienced in performance. Some form of documentation of the work for publicity and presentation purposes; for instance, in applying for funding, would at some stage be required, and this would be constructed for such a purpose.

**Staging the performance. Production requirements**

**Performance Venue**
In considering a performance venue, there are a number of important considerations. The venue needs to contain:

• Significant space to accommodate multiple participants. Recommend at least 3-metres height with a floor space at least 9-metres squared.
• Relatively low background noise required (external and internal) conducive to deep listening
• A degree of reverberation to enable the sine-tones to effectively propagate and combine
• Provision for exclusive use for set up and performances
• Quality lighting and sound equipment, with reliable technical support at hand

The performance venue chosen for the performance was the Yarra Edge Music Centre at NMIT Fairfield. This space exhibited all the qualities listed above.

**Sound**
The same sound reproduction technology used in the data-gathering phase was employed for the performance, including the same computer, audio interface and loudspeaker equipment, and their relative placement – one in each corner – as outlined in Chapter III (Figure 10 Page 26).
Lighting and vision

Lighting and vision are important considerations in creating an environment that allows participants to move freely and safely around the space, without creating distraction or impacting on considerations of comfort. Diffusion is an important consideration as it was found during the set-up that single point lights (typical of most theatrical fixtures) could have a discomfiting and distracting effect when engaging with the work.

In researching the literature related to this project, a number of images relating to wave theory kept cropping up. One image in particular clearly illustrates the effect of waves propagating and combining in water (Figure 13, below). The image also appeared to induce a sense of comfort and relaxation. The gentle ripples may invoke a calming effect. The color blue has been shown by Wexner (1954) to be the color most commonly associated with the ‘mood-tone’ of security and comfort. Research reliably correlates blue hues with lower pitch (Simpson, Quinn & Ausubel, 1956), and lower brightness levels with reduced loudness (Stevens & Marks, 1965; Root & Ross, 1965; Marks & Stevens, 1966). The color blue has been found to correlate perceptually with “pure tones” of low pitch and low loudness levels (Marks, 1974). These findings provided guidance for appropriate brightness, color and hue settings, which were mediated in the space by subjective decisions on visibility and safety.

Figure 13: Image used as inspiration for the lighting design and color palette. Origin unknown.
The Setting
The setting needs to be open and welcoming. The background sound level needs to be reduced as much as possible; therefore not all spaces are naturally conducive to this installation. Temperate climates are preferred as this reduces the reliance on noisy heating and cooling systems to obtain comfortable physical conditions.

The venue requires a foyer or antechamber for the audience to gather and receive written instructions. These were inspired by the written material provided to participants at Soundwalking events, as discussed in Chapter II (Page 19). The following figure (Figure 14) is a copy of the instructions given at this performance:

```markdown
Welcome.
Thank you for choosing to participate.
Your task in engaging with this sound installation is to seek comfort.

Listen deeply to the sound in - and of - the room.
How does it make you feel?
Is there a place in the room where you feel more comfortable?
Find it, and be in that place. If you lose it, find it again.
Continue throughout.
Always listening. Listening always.
Please remain silent throughout the performance.
Take care when moving around.
Duration: approximately 30 minutes.
You are free to leave at any time if you wish to do so.
Comments welcome on conclusion.
```

Figure 14: Written instructions as provided pre-performance
The following is an extract from notes I had written early in the development process which are included here to help visualize the performance setting from the perspective of a participant:

The audience gathers in a foyer. Written instructions are provided:
No definition of comfort is given. We are free to consider our own definition, and to engage with it. Our definition may change. The conditions may change.

A door opens and the audience are invited to enter the performance space. It is a large empty space bathed in subdued, diffused blue light. The eyes take a while to adjust. Sustained tones become apparent in the background. Gradually, subtle tones set at unison 100Hz fade in from each speaker, very quietly in the background. In response to the directions, the audience members begin to seek comfort.

The tones are at first in unison, but then, after a minute, they cross fade with a new combination and a new tonal relationship emerges. During the cross-fade, a total of two tones emanate from each loudspeaker. Following the full course of the cross-fade, each loudspeaker returns to producing a single sine-tone, now set at a different pitch to the previous state, thus, between cross-fades, the only combination of tone is in the room. After two minutes, another cross-fade introduces the second tone to each speaker a new tonal combination occurs, and these tonal coincidences change again once the cross-fade is complete and the third set of tones exists. This cycle of cross-fade to new tone combinations happens several times throughout the 30-minute performance. The final set fades out over 2-minutes to reveal the natural sonic state of the room. The audience are free to leave whenever they feel comfortable to do so.

The premiere season of performances occurred between Friday 30th September 2011 and Saturday 8th October 2011. There were eight performances in total.

The following chapter evaluates the effectiveness of the planned installation and discusses feedback and findings based on personal and anecdotal evidence offered voluntarily by audience participants following the performances.
CHAPTER V. FINDINGS AND EVALUATION

In this chapter, I will discuss findings and evaluation of the premiere performance installation season, and relate some of the anecdotal evidence of the audience experience, with proposals for further research and development.

The installation was set-up as planned and discussed in the previous chapter. There were no major technical or logistic difficulties, and the performances proceeded as scheduled.

The number of participants at each performance varied between three and ten, with the average size being six. This average seemed an ideal number. More participants would significantly change the nature and the context of the performance as crowding would have a high impact on perceptions of personal space and relative individual comfort.

Various combinations of lighting fixtures and placement were tested for appropriate illumination and diffusion effects. Some ceiling mounted single source fixtures were used in addition floor fixtures illuminating the walls; however, the ceiling fixtures were discontinued following the first performance when participants found them too bright and distracting while laying on the floor.

Post Performance Discussions

There was a strong tendency for participants to linger and engage voluntarily in discussions following each performance. Even though there was a 30-minute gap between performances, these discussions were often cut short as attendees for the next performance gathered. It seemed naturally inappropriate to discuss the work with those who had not yet experienced it.
The anecdotal evidence was broad, and the experiences contrasting. The main topics of discussion were the emission and propagation of sine tones, and the notion of comfort.

**Comments on the emission and propagation of sine tones**

Some participants were confused about where the sound was coming from. There was a general acceptance that the speakers visible in each corner must be the source, but some participants doubted that the speakers were emitting any sound at all, even when standing directly in front. When told that each speaker was always emitting at least one tone, sometimes two, some participants found it hard to believe. This relates to the psycho-acoustic behavior of sine tones as described by the Fransen effect and other illusions, the effect of interference and phase cancelation, and the difficulty associated in locating the direction of low frequency sine-tones.

**Comments on the notion of comfort:**

On the whole, participants were able to attain a sense of comfort. For some this happened quickly, for others it took some time. Many issues emerged as impacting directly on levels of comfort. Some related to the sound content, while others found that personal, emotional, cultural and political considerations influenced the experience. Some participants felt uncomfortable because they had never before participated in anything similar, however, over time and with the growing familiarity with the piece, a sense of comfort developed.

Some participants felt that a quest for comfort gave way to a sense of playfulness in locating the place of most pronounced aural effects. This usually occurs at the nodes of maximum phase cancellation. At these “sweet spots”, very small movements, sometimes as little as a left-right head rotation, at other locations a distance of one step, could result in significant aural variation. These movements produced some unexpected choreographic elements. This led on several occasions to imitative behavior in other participants seeking to investigate the effect. The notion of comfort became a quest for experience and playfulness.

Some participants found more comfort in small confined movements, while others made use of the entire space.
For some participants, the notion of comfort was directly affected by the actions of those around them. This could become a source of discomfort and distraction; however, it was suggested that once familiarity with the space and fellow participants developed, the considerations of comfort shifted to a more personal sound/space consideration. By contrast, those with previous deep listening or meditation experience claimed to be able to employ these skills to move more quickly into an immersive interactive relationship with the installation.

Echoing some of the anecdotal evidence from the performances by Fontana as described in the Introduction on page 1, some participants commented on the distortion of their sense of time, suggesting the piece felt much shorter than the 30-minute duration.

Summary

Personal experience, observation and anecdotal evidence generated by the premiere performance series serves to reinforce the findings of the preliminary research and addresses the research questions posed in Chapter I in the following ways:

• Considerations of personal comfort levels can serve as an appropriate means by which to engage and explore a sonically enhanced physical environment
• Our sense of comfort can be affected by subtle changes in pitch and amplitude relationships within a sustained tone environment.
• Consonant combinations of sustained tones, where tones are considered stable, or at rest, are considered relatively more comfortable than dissonant combinations, where tones are considered unstable, active, or restless, although it is possible to form positive relationships with dissonant textures set at subtle levels, and through active listening and selective engagement such as playfulness
• Many psychological and physiological effects occur when engaging with subtle sustained low frequency sine-tone environments. The unnatural nature of sine-tones set at subtle levels and at low frequencies serves to disconnect the sound from the sound source.
• It is not possible to predict individual personal comfort preferences in response to subtle sustained sine-tone environments. This is due in part to the broad range
of habitual and learned listening abilities, and contrasts in the definition and manifestation of comfort among participants. While it is reasonable to suggest that comfort for some participants clearly relates to consonance and stillness, this is not always the case, and the experience remains unique for each individual. Each person composes and performs a unique and intimately personal variation. This remains a tantalizing possible extension of this research.

- A high degree of interest, willingness and intrigue in the concept and performative realisation of the piece exists. Engagement with the strong articulation of sound propagation effects throughout the space being one of the most notable experiential highlights.

Further work

The research conducted as part of this project is far from conclusive. Further work is required to understand more clearly the sophisticated comfort responses and modes of engagement with subtle sustained sine-tone environments.

It is acknowledged as a possible extension of this work to set levels in the venue subjectively by ear, and then measure the levels using a dB meter to determine the precise physical nature of the sound/space. This would present data coincidental to each venue, and interest lays in the comparison subjective engagement across a range of sound spaces.

The ability to track the movement of individual participants throughout a performance is one possible research pathway. A number of video-based object tracking systems currently exist that may be useful in generating extensive data on the direction, speed and range of movement of individual participants. This process “uses non-identifiable tracings of movement and presents the resulting information in a way that can be easily parsed and quantified, thus creating an opportunity to see trends in the motion” (Steffen & Alsop, 2009).

Another possible extension to the work would be to investigate ways of recording and documenting the aural experience of each participant. This would require the collection of audio data at the point source. In this case, the point source is wherever each participant happens to be at any given time. This presents some unique research and
design challenges that would require research into how to adequately, practically and reliably capture, store and analyze the considerably large amount of audio data required to accurately describe a mobile aural experience with 360-degree perception over a 30-minute duration.
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APPENDIX I:

Significant examples and applications of sustained tone and sine-tones in music

Sustained sound as a vehicle for engagement
The use of sustained sound as a musical device – often referred to as a drone - is a universal phenomenon. It can be found as a continuous underpinning temporal structure to harmonic and melodic elements in many diverse and geographically distinct cultures. It is present in the music of indigenous Australia in the form of the didgeridoo, the singing tradition of Tuva in central Asia, the bagpipe traditions of many European nations, the sitar and tampura instruments used in India and neighboring countries, European fiddles and zithers such as the Norwegian Hardanger fiddle and Langeleik droned zither, and the related Appalachian Dulcimer. Drone has also been linked with religious and spiritual activities in many different cultures, where sustained sound is used as a carrier toward a state of trance or meditation, such as the chanting of Buddhist monks and long sustained vocalizations in many Sufi, yoga and meditation traditions.

Composers and compositions using sustained textures
In contemporary culture, drone is a common musical device in theatre and film and is used to enhance emotional sub-texts such as suspense, anticipation, tension and expectation (Stilwell, 1997).

Western classical music contains examples of this device where the composer seeks to invoke references to folk traditions such as those referenced above. An often-quoted example of “harmonic stasis” (Bamberger, 1968) in the classical repertory is the Prelude to Wagner's Rheingold featuring a sustained E-flat major throughout. In The Unanswered Question by Charles Ives, sustained diatonic chords in the strings underlay the increasingly dissonant dialogue between the woodwinds and trumpet.

Sustained sound as a musical device features in the work of minimalist composer La Monte Young. Young was drawn to the use of long, sustained and simple musical
textures, and in some cases this constituted the entire piece. Composition 1960 #7 contained two notes – B and F#, a perfect fifth, with the instruction: "To be held for a long time." He differed from other minimalist composers such as Glass and Reich who focused on neo-classical devices such as ostinatos, simple tonalities, repetitive rhythm and arpeggio structures. (Potter, 2002). Young was focused on sustained tones as a way of getting “inside the sound” (Sun, 2006). Perhaps the ultimate sine-tone composition is Young’s Dream House, a body of work including published works, performances, installation and collaborations based on sustained tone content over long time periods. The longest single Dream House performance lasted uninterruptedly for six years, from 1979-1985. The work is in collaboration with visual artist Marian Zazeela, members of the Theatre of Eternal Music and other invited guests (Duckworth & Fleming, 1996). The current Dream House celebrates 20 years in 2012-13. Young’s extensive body of work, particularly since the early 90’s, is difficult to confront and warrants much deeper consideration and investigation in the context of future developments of the work outlined in this dissertation.

Maryanne Amacher’s work features complex sustained electronic textures with wide dynamic range, and was primarily installation-based. The audience experienced “the spatial placement of sounds” (Borchert, 1997 p. 89) by moving through the space. Extreme variations in volume and texture, performed live through a process of “electronically altering, remixing, and rebalancing the sounds as they happen” (Borchert, 1997 p. 89), are the major factors in the music’s effect. The experience for the audience was far from subtle. Gann (1988) uses terms such as “bombarded,” “collisions,” and “deafening” in a review of Amacher’s work. Armacher was interested in Otoacoustic Emission, a physiological phenomenon where sound stimulus at certain frequency and intensity produces additional tones in the inner ear. Research remains scant in this area, and it is not entirely clear whether the phenomenon is distinct from combination and difference tones.

Phil Niblock creates very dense microtonal textures that evolve gradually over long durations. Sound sources are mixed and often comprise held instrument tones extended by editing out the breathing to create continuous tones. (Hainge, 2004). Niblock often combines these complex tonal textures with moving image. In the DVD *The Movement of People Working* (Niblock, 2003), the repetitive rhythmic actions of
people engaged in manual labor set against dense sustained sonic textures may seem dichotomous but produces a compelling hypnotic continuum.

Maggie Payne processes the recordings of musical instruments and location recordings to create extremely complex and slowly evolving sonic universes that are best experienced with closed eyes and deep listening techniques to fully appreciate the subtle sonic intricacies as they are revealed. (Borchert, 1997)

Taking sustained tone textures to an extreme dimension is Longplayer by Jem Finer. This piece is designed to play continuously for one thousand years. It began playing at midnight on the 31st of December 1999, and will continue to play without repetition until the last moment of 2999, at which point it will complete its cycle and begin again. It uses Tibetan singing bowl waveforms played at various pitches and intensities. A long sustaining tone characterizes the sound, and notes overlap, creating sustained textures of varying intensity. (Longplayer Trust, 2012)

**Composers and compositions using sustained sine-tone textures**

Many composers have employed electronic generated sine-tones as part of their work. Some have composed pieces using sine-tones alone, with examples tracing back through Stockhausen and cohorts at Cologne University in the 1950’s to the invention of the electronic oscillator in the 1920’s. Fewer have focused exclusively on sustained sine-tones textures, and a thorough review of these works reveals very few works of exclusively sustained sine-tone textures presented as sound design installations. The following is a brief account of some notable examples.

Alvin Lucier’s exploration of acoustic phenomena and auditory perception includes pieces exploiting sustained sine-tone textures as installations. Conceived and developed from 1973, “Still and Moving Lines of Silence in Families of Hyperbolas” consists of four versions, or applications, two for gallery installations, one for record, and one for dance. The recorded version (1974/2002) combines steady and sweeping electronically generated sine tones with instruments such as marimba and clarinet, and explores some of the aural illusions outlined in earlier chapters such as the glissandi effect. The gallery versions are with or without percussion. In the absence of percussion, sine-tones alone are used to explore the same illusory effects as the recorded version, as
well as exploiting interference tones and phase cancellation effects introduced by the resonant characteristics of the space.

Sine Field by Jason Kahn (2003) uses high frequency sine tones between 10Khz and 18 KHz as very low amplitude. Kahn asks: “where does the perception of sound begin and how much of this perception occurs on a strictly physical as opposed to a psycho-acoustic level; and how is our spatial orientation determined in a field of sound where the acoustic reference points are always changing?” (Kahn 2003).

Sonic Network No. 9 by painter John Aslanidis and musician Brian May (2011) comprises a generative sound piece made entirely of sine tones that responds to the textural components of four large painted panels, each created according to a set of mathematical intervals. The sound component is generated in response to the textural component of the paintings. Overlapping sine tones fade in and out in at varying pitches and durations to create a sustained sinusoidal texture continuously evolving for the duration of the exhibition.

_Anasiseiψychos_ (for 16 sine-tone generators) by Marinos Koutsomichalis (2009) was composed to challenge the specific architectural and aesthetic qualities of the Trevor Jones Studio in York, UK. Multiple sine-tone glissandi at intense amplitude settings provoked perceptual side effects and visceral reactions to sound. In an attempt to establish a spiritual bond with the location, the composer performed a collection of these pieces without an audience. Recordings were made but considered an irrelevant by-product; the work was designed and conceived to exist only for the composer and the space.
APPENDIX 2:

_ A guide to re/creating the composition_

You are welcome to recreate this piece for personal, educational or performance purposes, using the guidelines below, and in line with the compositional and presentation process as outlined in this dissertation. Please notify the author prior to any public presentation. Appropriate acknowledgement and attributions required.

The sound set-up must maintain discrete routing of four mono outputs to four separate loudspeakers, with speakers placed as illustrated in Figure 10 on page 26.

The following three recreation methods require low-level reconstruction. These are:

1. Using the raw sine-tone sound files contained in the accompanying materials
2. Using independent tone generators and constructing a live mix
3. Using software to construct a generative synthesis approach

In each method above, the layering and temporal placement outlined in the blocked timeline (Figure 12 on page 36), and output allocations, cross-fades and relative amplitude detailed in Table 2 (page 28) should guide the construction and presentation process.

A fourth approach requires less construction, and makes use of the four mono stems contained in the accompanying materials. Each stem is a bounce of each of the four discrete layers, and includes all tones, fades and relative levels as used in the 30-minute performance detailed in Chapter IV. Import each file to a mono audio track and route each track to one or four discrete outputs, which in turn are sent directly to one of four loudspeakers.
Title:
Simple subtle sustained waveforms and the notion of comfort in a new approach to creating
an immersive, interactive sound installation

Date:
2012

Citation:
approach to creating an immersive, interactive sound installation. Masters Research thesis,
Faculty of VCA and MCM, The University of Melbourne.

Persistent Link:
http://hdl.handle.net/11343/37737

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