SPECTRAL, SPATIAL AND TEMPORAL COMPLEXITY IN ELECTROACOUSTIC COMPOSITION: A STATISTICAL, THEORETICAL AND COGNITIVE ANALYSIS OF FLUCTUATION IN MORPHOLOGICAL FORM

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A thesis submitted in partial fulfilment of

requirements for the degree of

Doctor of Philosophy

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Statement of Originality

I declare that the research presented here is my own original work and has not been submitted to any other institution for the award of a degree.

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Declarations

The research protocols of this thesis were reviewed and approved by the appropriate research ethics board to ensure the protection of participants' rights and well-being (HREC 2021/322, Appendix F). Informed consent was obtained all participants, and their anonymity and confidentiality were maintained.

Abstract

This thesis investigates the relationship between the varying complexities of spectromorphology, spatiomorphology and temporal morphologies, their visualisations in computer music notation and the impacts of each on listener preference and understanding in electroacoustic settings. An analysis of existing theoretical examples and visualisations of Smalley's (1986, 1996, 1997) sound-shape are presented alongside a notational system developed to explore ways in which morphological complexity can be articulated visually and translated into compositional practice. A series of musical experiments and perceptual tests are presented, demonstrating that higher rates of morphological complexity and fluctuation lead to increased listener preference, interest and understanding of both short auditory stimuli and longer electroacoustic compositions. A composition portfolio informed by the results of both analyses and notational system is presented. A discussion of this portfolio alongside subsequent cognitive enquiry examines ways in which to inform future directions of electroacoustic composition, notation, diffusion, analysis and experience in technologically driven environments.

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For M & Z.

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CHAPTER ONE

Introduction

1.1 Background

Technology has revolutionised the way in which sound is experienced in musical spaces (Smalley 1996). As electroacoustic music continues to evolve, it becomes imperative to comprehend the impacts of morphological complexity and fluctuation on the experiences and perceptions of listeners. In its various forms, musical complexity assumes a pivotal role in shaping listener experiences, evoking heightened emotional, cognitive, and aesthetic responses through intricate musical structures and textures (see Dean & Bailes 2016; Bailes & Dean 2007, 2012; McAdams, Douglas, & Vempala 2017). Existing research has predominantly focused on analysing musicological discourse and aural interpretation within the context of morphological articulation in electroacoustic music (see Smalley 1996, 1997; Emmerson & Landy 2016; Blackburn 2011;Young 2004; Harrison 2013). The next challenge is to gain an understanding of listener experiences in relation to varying degrees of morphological complexity or fluctuation. Empirical evidence is needed to effectively demonstrate the impacts of morphological articulation on the listener's experience.

The primary aim of this thesis is to explore the role of morphological complexity, fluctuation, and form as by-products of electroacoustic music, investigating their subsequent impacts on listener understanding and interest in electroacoustic music. By doing so, this thesis seeks to gather valuable insights on listener preference that inform future compositional and notational processes. The subjective nature of morphology arises from its dependence on listener perception and interpretation. Consequently, establishing consistent understandings and analyses of morphological value in electroacoustic music proves challenging for composers and researchers alike with a lack of globally objective or quantifiable measures. To overcome this obstacle, this thesis will establish links between standardized notation systems of morphology and value-based acoustic analyses and perceptual testing.

1.2 Research Aims

This research aims to make contributions to the theoretical and practical advancements in computer-based music by exploring the links between *sound-shape* notation, morphological complexity, compositional methods, and their correlation to perceptual experience. The primary objectives of this thesis can be summarized as follows:

Objective 1. To examine the impact of various morphological complexities (spectral, spatial, temporal and amplitude) on listener perception, preference, and understanding of electroacoustic stimuli and music.

Objective 2. To explore and develop a notation system that effectively represents spatial and morphological information in electroacoustic music.

Objective 3. To identify and understand the correlations between sonic parameters and perceptual dimensions.

Objective 4. To apply the research findings to the creation of an expanded composition portfolio that enhances preference, complexity, interest, and completeness.

To guide these investigations, this thesis will address the following research questions:

Research Question 1. Do varying levels of spectral, spatial, amplitude, and temporal morphological complexity influence listener preference and understanding of electroacoustic music?

Research Question 2. What is the impact of morphological fluctuations on the aesthetic appeal and emotional engagement of the music?

Research Question 3. What are the practical implications of incorporating morphological features in notation systems and subsequent compositions?

By addressing these questions though a combination of empirical research, theoretical exploration, and practical implementation, this thesis will advance understanding of how morphological complexities shape listener experiences and determine new trajectories in music composition and notation systems.

1.3 Thesis and Portfolio Structure

This thesis follows the following structure:

Chapter 2: Literature Review: Extensive review of existing literature on electroacoustic music composition, perception, and analysis, focusing on sound-shape notation, morphological complexity, notational methods, and listener responses.

Chapter 3: Study One: Investigates the interplay between spectromorphological complexity and listener perception through deliberate spectral manipulation of electroacoustic stimuli.

Chapter 4: Study Two: Explores the effects of spatial, temporal, and amplitude morphologies on listener experiences in short auditory stimuli.

Chapter 5: Study Three: Building upon the insights gained from Studies 1 and 2, this Chapter examines the visual relationship between morphology, structural complexity, and electroacoustic music notation, exploring the incorporation of morphological dimensions in notation systems.

Chapter 6: Study Four: Serving as a proof of concept, this chapter analyses longer forms of electroacoustic music to understand the compositional potential and impact of morphological fluctuation on listener experiences.

Chapter 7: Composition Portfolio: This chapter acts as a critical examination of an adjoining composition portfolio, which serves as a practical manifestation of the research findings of Studies 1 – 4

Chapter 8: Summary of Findings: Summarizes the key findings and implications of the conducted studies.

Chapter 9: Conclusion: Concludes the thesis.

1.4 Significance

The investigation into the relationship between complexity, notation, and listener response will provide valuable insights into the compositional process and the reception of electroacoustic compositions. Understanding how complexity influences listener preferences, understanding, and enjoyment can inform composers in creating captivating musical experiences that resonate deeply with audiences. The insights gained from this study can inform the development of new compositional techniques, notational systems, and pedagogical approaches, facilitating the growth of the electroacoustic genre and encouraging further artistic exploration.

1.5 Definitions

DEFINITION 1.1 Complexity: The use of the term *complexity* within this thesis refers to the intricate arrangement and control of acoustic and morphological parameters within sound. These parameters encompass spectral (frequency components), spatial (sound placement and motion), temporal (timing and rhythm), amplitude (volume changes), textural (sound density), and spectromorphological (spectral and morphological characteristics) elements.

DEFINITION 1.2 Completeness: In the context of this thesis, *completeness* refers to the extent to which a sound or sonic event contains a full and rich set of morphological characteristics. It involves the presence of diverse and nuanced spectral components and morphological features that contribute to the overall richness of texture, depth, and complexity of a sound. This thesis discusses *completeness* in both objective assessments but also subjective perceptions. For example, objective spectromorphological completeness suggests that a sound exhibits a wide range of spectral and morphological attributes, whereas the subjective perception of perceived completeness would suggest a listener feels the sound feels rich and full. Achieving spectromorphological completeness involves careful attention to the spectral and morphological attributes of a sound, ensuring that it is not overly simplistic but instead exhibits depth and intricacy that can captivate and immerse the listener.

DEFINITION 1.3 Expressiveness: In this thesis, *expressiveness* relates to the deliberate manipulation or interplay of spectral, spatial, temporal, and dynamic morphologies within sound or compositions to convey specific feelings or artistic intent. This includes adjusting harmonic structure, temporal dynamics, spatial features, and timbre to evoke emotional responses. It encompasses both compositional choices and how listeners perceive and respond to the sound.

CHAPTER TWO

Literature Review

2.1 Introduction

The field of electroacoustic music composition encompasses a complex interplay between compositional intent, technological complexity, and the subsequent intentional manipulation of morphologies (see Xenakis 1971; Smalley 1997; Thoresen 2007; Otondo 2008; Spencer 2017). This literature review aims to provide a comprehensive analysis of existing research in this domain, with a focus on notation systems, complexity in music, listener response, and the integration of audio plugins and technologies. By examining existing studies and their research findings, this review seeks to identify key insights, theories, and gaps in knowledge, ultimately guiding subsequent studies in this thesis to advance our understanding of electroacoustic music composition.

The integration of technologies such as digital audio workstations, digital effect processors spatial technologies and audio plugins have revolutionized the landscape of music production and composition (see Landy 2007; Emmerson & Landy 2016; Chafe 2018; Cross 2019). Technology, as a tool, offers an extensive range of sound manipulation capabilities that can profoundly shape and transform musical materials (Lyon 2014; Barrett 2015; Lippe 1992; Adkins, Scott & Tremblay 2016; Wanderley & Battier 2001; Cross 2018b). By investigating the existing body of knowledge this chapter aims to shed light on the intricate relationships between technology, morphological complexity, and listener perception in electroacoustic music composition. Understanding these dynamics will pave the way for deeper insights into the creative process, composition intent, and the potential for technological innovation and immersive musical experiences. Ultimately, this review serves as a critical foundation for the subsequent studies conducted within this thesis, which seek to expand our understanding of electroacoustic music composition and its multifaceted relationship with perception and technology.

2.2 Morphological Complexity

Electroacoustic music provides a unique avenue for investigating the intricate relationship between sound and listener perception (Young 2004). As highlighted above, electroacoustic music creation and analysis has witnessed significant advancements, embracing new technologies and compositional techniques. Such heightened manipulation of sound raises important questions regarding the morphological properties of electroacoustic compositions and their impact on perceptual understanding and enjoyment. To unravel the perceptual and cognitive mechanisms underlying the processing of complex auditory scenes, it is essential to comprehend the role of morphological form, fluctuation, and complexity. This section aims to explore existing research on how these factors influence perceptual experiences in the context of electroacoustic music composition.

The integration of spatial distribution in electroacoustic music adds another layer of complexity to listener perception. Spatialization techniques, such as panning, reverberation, and spatial movement, can significantly influence the listener's experience and emotional response (Danieli, Witek & Haworth 2021). However, the interaction between spectral complexity and spatialization has received limited attention in research. Understanding how spatial cues interact with spectromorphological complexity can contribute to the development of more immersive and engaging electroacoustic compositions. In addition to spectral and spatial complexity, the temporal dimension plays a crucial role in listener perception. Temporal factors, including rhythmic patterns, temporal fluctuations, and dynamic changes, shape the listener's sense of time, expectation, and anticipation (Patel 2010). Moreover, temporal complexity can affect the listener's engagement, attention, and emotional response to the music (Barthet et al. 2011). Investigating the interplay between spectral, spatial, and temporal complexity can provide a comprehensive understanding of how these dimensions collectively shape listener perception in electroacoustic music.

Multiple elements contribute to the complexity of music, including rhythm, melody, harmony, texture, and form (Pearce & Müllensiefen 2017; Haumann et al. 2018; de Berardinis 2022). Neurologically, complex rhythmic patterns, irregular meters, syncopation, and polyrhythms challenge listeners' ability to predict and synchronize with the music, adding layers of complexity to the overall experience (Van Noorden & Moelants 2010; Patel 2010; Henry et al. 2017; Bouwer et al. 2018). Melodic intricacy and harmonic richness demand listeners' attention through the use of chromaticism, dissonance, extended chords, and unconventional tonal progressions (Di Stefano et al. 2017). Similarly, the intricate amalgamation of timbral combinations has been found to impact listener perception (Barthet et al. 2011; Eerola, Ferrer & Alluri 2012). These types of structural complexities can impact listener perception, as non-traditional forms challenge listeners' expectations and require active engagement (Huron 2006; 2019). Most quantitative research in this domain has focused on general sound stimuli without considering the temporal, spatial, or spectral capabilities of digital output. These studies demonstrate that increased rates of spectral features in auditory stimuli positively impact listener perception, preference, and understanding. However, the effects of morphologies on perceptual experience remain unexplored. Furthermore, little attention has been given to the granular effects of technical or computer-based modulation on acoustic stimuli in composition.

In the analysis and interpretation of electroacoustic music, a comprehensive understanding of complexity is crucial. Furthermore, an understanding the morphological form is crucial for comprehending complex auditory scenes in various domains (see Smalley 1986, 1996; Tanzi, 2011; Holbrook, 2019). While existing studies have primarily focused on separate aspects of morphological articulation in electroacoustic music, including musicological discourse, aural interpretation, and acoustic structure (Emmerson & Landy 2016; Blackburn 2011; Young 2004; Harrison, 2013; Bailes & Dean 2007, 2012), the combined methodologies of morphological and acoustic structural analysis are seldom considered together. The links between acoustic analysis, morphology and their tangible impacts on human perception remain largely unexplored. By leveraging off the above fields of research to define, link and assess complexity both morphologically and acoustically, an objective framework can be articulated for subsequent testing on the perceptual impacts of morphology on listeners.

Establishing a connection between spectromorphology models and modern acoustic analysis is a complex task. While the above studies offer valuable insights into the acoustic analysis of morphological form, and the complexity of sound, there are still gaps that need to be addressed. Specifically, more studies are required to explore the relationships between morphology and perceptual responses. By comprehensively understanding the various elements that contribute to complexity perception, exploring the intersections between acoustic and perceptual analysis techniques, and considering the impact of spatiotemporal morphologies, we can advance our knowledge of how listeners perceive and engage with electroacoustic compositions. As such, this thesis should further investigate the intricate relationships between compositional intent, technological complexity, and perceptual understanding in the field of electroacoustic music composition. Additionally, a model that is measuring spectromorphology and aligning it with objective measures in modern acoustics, bioacoustics, and signal processing analysis should be established.

2.3 Representing and Notating Morphological Complexity

This section highlights the challenges of representing electroacoustic music through traditional notation systems, discusses alternative approaches proposed by notable scholars in the field, and identifies the need for further research to overcome the limitations and develop more accurate and comprehensive notation systems for electroacoustic music. Technological advancements have expanded the possibilities for manipulating and generating complex acoustic stimuli. As articulated above, digital signal processing techniques allow composers to create intricate spectromorphological structures, precise spatialization, and intricate temporal patterns. Systematically manipulating and controlling these parameters provides an opportunity to investigate their impact on listener perception in a controlled experimental setting. Effectively notating in this medium necessitates a comprehensive understanding of the acoustic properties of sound, their morphologies, and the perceptual mechanisms of their subsequent sound-shapes. The use of notation in electroacoustic composition is vital in keeping up with the technological complexity of the medium, enabling composers to communicate their creative ideas, guide performers, and ensure accurate and consistent realisation of their works. Despite this, representing and communicating morphological ideas effectively poses a significant challenge for composers (Young 2004), as the understanding and interpretation of morphology in electroacoustic music are subjective and rely on individual perception and interpretation (Patton, 2007; Blackburn 2010; Dunkelman 1995, cited in Couprie 2011; Berquin 2011; Boulez in Merlier 2011). This subjective nature makes it difficult to establish a consistent understanding and analysis of morphological complexities in electroacoustic music.

Looking at the fabric of sound structures, the relationship between spectral, spatial and temporal notation should be considered a fundamental component of morphology. Theoretically they are fused (Smalley 1997; Holbrook 2019; Lotis 2003, 2011), but visually they are often treated separately (see Fischman 1998; Hirst 2011; Spencer 2017; Nyström 2011, 2017). While spectral and temporal properties of the sound-shape are representative of modern notational influence (see Blackburn 2010), space is often notated using less linear techniques (Harley 1996, 1997; Kim-Boyle 2014, 2019), or in a way that strays from the propriety of Smalley's visual sound shape (Boulez in Merlier 2011; Justel 2011; Anderson 2015). Capturing and compositing these varied morphological features poses difficulties when it comes to notating the music in a way that accurately conveys the intended sonic experience to performers and listeners.

Traditional music notation systems, designed for acoustic instruments, often fall short in capturing the spatial, spectral, and temporal dimensions inherent in electroacoustic compositions. Without a system in which to accurately notate the coordinates of sound in these spatial settings, the notation of space will always be loose and general. Blackburn (2011) addressed how toward the visualisation of space should utilise a 'three-dimensional canvas' to present a more accurate picture of spatial sound organisation. Additional contributions in this area have developed innovative notation systems that address the unique characteristics of electroacoustic works (see Blackburn 2011; Ellberger et al. 2016; Smalley 1996). Despite this, no visualization currently exists articulating the actuality or degree of such height, width or depth in Cartesian environments, with studies either straying from the notion of Smalley's sound shape visualisation (Ham 2017; Bacon 2022; Carinola & Geoffrey 2022; Merlier 2018), pivoting toward spatial performance (Gorne 2015; Garavaglia 2016; Barrett 2016) or placing an emphasis on static speaker placement and not the notation of sound across space itself (Couprie 2005, cited in Couprie 2011; Duchenne 1991; Berezan 2011; Justel 2011; Schlienger and Khashchanskiy 2021). Alternative approaches, such as graphical representations, value-based symbolic notations, and hybrid systems should be raised in this thesis to address these challenges.

2.4 Perceptual Testing

Complexity in music is a topic of great interest in music psychology and aesthetics. Understanding how listeners perceive and respond to electroacoustic music is crucial for composers and performers in this genre. The discourse of electroacoustic music emphasizes the importance of morphological context in understanding listener perception (Smalley 1996; 2007). The morphological and acoustic complexities of sound, particularly in spectral, spatial, temporal, and amplitude capacities, play a crucial role in electroacoustic music. While previous studies have analysed specific aspects of spectral properties (Tervaniemi et al. 2000; McAdams et al. 2004; Gingras et al. 2013), non-spectromorphological perspectives (Emmerson 2007; Schumacher 2021) or overall pitch and rhythm structures (Honingh et al. 2015), little is known about the direct impact of spectromorphological ties on listener perception, preference, understanding, and satisfaction. As such, this thesis should explore the influence of acoustic features on listener perception in a spectromorphological context and investigate how varying complexities of spectral morphology may impact the listener's experience.

Studies have shown that increased complexity can evoke heightened emotional and cognitive responses in listeners (Huron 2006, 2019; Grewe et al. 2007; Juslin et al. 2008). Huron’s concept of "informational complexity" aims to quantify and understand the processes involved in perceiving and processing musical information. Similarly, technological advancements have transformed acoustic reality and influenced the brain's response to acoustic cues (Stenslie 2006; Wang 2013; Cross 2018a; Cruces-Solís et al. 2018). Studies have indicated that increasing acoustic complexity, particularly through harmonic information, leads to heightened neurological responses (Kuriki et al. 2007; Tremblay 2007; Tervaniemi et al. 2000). However, there is little understanding of how discrete spectral components impact a listener's perceptual preference, interest, or assumption of sonic experience on a subjective level of enjoyability. Furthermore, the spectral complexity of auditory stimuli elicits heightened perceptual responses in listeners. Studies conducted by Kuriki et al. (2007), Shahin et al. (2005), Bardy, Van Dunn & Dillion (2015) indicate that spectrally complex sounds with additional harmonics evoke enhanced neural responses and greater perceptual sensitivities.

Several characteristics of electroacoustic music have been found to correspond with measures of affect. Isolated perceptual preference and contrast effect tests have demonstrated that acoustic complexity can significantly impact listener arousal, preference, and emotional response to musical stimuli (Bailes & Dean 2012; Dean, Bailes & Schubert 2011; Lloyd et al. 2018; Smit et al. 2022; Juslin & Vastfjall 2008). Spectral, structural, timbral, and spatial structures have been determined to influence listener experience (McAdams, Douglas, & Vempala 2017; Caclin et al. 2005; Juslin & Laukka 2004). Similarly, the inclusion of intricate patterns and fluctuations within brief cues has been found to significantly enhance the aesthetic appeal and emotional impact on listeners (Schubert 2013; Barthet et al. 2010). However, little attention has been paid to understanding listener experience to varying degrees of morphological complexity in compositional settings. It becomes pivotal to understand if rates of morphology are closely linked to increased listener enjoyment, particularly in the context of short spectral cues, positively impacting the subjective experiences and understandings of listeners. The next challenge is to create empirical evidence that illustrates how morphological articulation affects listener experience.

In the domain of electroacoustic music research, various perceptual testing methods have been employed, including surveys (Juslin & Laukka 2004; Kamalzadeh, Baur & Möller 2016) Likert scales (Eerola, Ferrer & Alluri 2012; Broughton, Dimmick & Dean 2021) and paired comparison tests (Lloyd et al. 2018). Lloyd et al. (2018) utilized paired comparison tests to investigate the perceptual ramifications of morphological complexity, ultimately uncovering that higher levels of complexity were perceived as more engaging and intellectually stimulating. Findings such as these underscore the importance of considering fluctuation as a significant factor in understanding perceptual responses to complex auditory scenes.

Perceptual testing serves as a fundamental tool in comprehending the subjective experiences and responses evoked by electroacoustic music, with specific attention to the intricate nature of morphological complexity. A review of the existing literature on perceptual testing methodologies in electroacoustic music reveals certain knowledge gaps that underscore the importance of further exploration in this field. Though previous studies have outlined the potential of electroacoustic music to evoke a wide range of emotional and aesthetic responses, further work is needed to understand the impact of morphologies. Various perceptual testing methodologies have been effective in this field. While existing research has demonstrated the aesthetic appeal and perceptual effects of complex compositions, but further studies are needed to explore the effects of morphological complexity and fluctuation on listener experience and the underlying mechanisms of perceptual responses.

2.5 Conclusion

This literature review has highlighted the significance of investigating the perceptual dimensions of spectral, spatial, amplitude, and temporal complexity in electroacoustic music. Understanding how these dimensions influence listener perception, preference, engagement, and emotional response is crucial for composers and sound designers to make informed creative decisions and craft immersive and captivating compositions. Furthermore, this research contributes to the development of models and frameworks for analysing and describing the complex and dynamic nature of electroacoustic music. However, despite the existing research in the field, there are still knowledge gaps and limitations that need to be addressed. There is a need for systematic investigation into the specific contributions of different dimensions of complexity and their correlations with positive listener experiences. Additionally, the development and refinement of notation systems for electroacoustic music should be a focus of further research to effectively capture the intricate morphological complexity and fluctuations in this genre.

Further exploration is also required regarding the perception of complexity in diverse musical traditions and genres, considering cultural and contextual factors that influence the perception of complexity. Examining individual differences and their impact on listener response, such as musical training, familiarity with the genre, and cognitive factors, can provide valuable insights. Addressing these gaps and limitations will enhance our understanding of electroacoustic music as a complex art form and facilitate artistic expression, creative exploration, and interdisciplinary collaboration. The subsequent papers in this thesis will build upon this foundation and aim to address these identified gaps in the literature. These studies aim to contribute to the field by deepening understanding of morphological complexity and its impact on listener experience in electroacoustic settings. Each subsequent chapter will provide a detailed overview of the methodology, analysis, and findings from each study, expanding upon the topics discussed in this literature review to offer new insights and perspectives.

CHAPTER THREE

Complexities of Spectromorphology

3.1 Introduction

This chapter addresses the challenges discussed in the previous literature review by examining the impact of spectromorphological complexity on listener preference, experience, and understanding of short electroacoustic stimuli. Through statistical analyses of electroacoustic stimuli and subsequent perceptual responses, the objective of this study is to investigate the role of spectromorphological structure, gesture and form on listener perception. The stimuli used in Paper 1 can be found in Appendix A.

PAPER 1

Cross, T. (in review a). Time series analyses of subjective perceptual responses to variable spectromorphological complexity in electroacoustic stimuli. ***Journal of New Music Research.***

Reframing Sound-Shapes in Spectromorphological Composition: Notating Perspectival Space Through Spherical, Euclidean and Cartesian-Coordinate Systems *(in press)*

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This paper will examine Smalley's preliminary taxonomy of the *sound-shape* and the subsequent application of graphical notation in electroacoustic music. It will demonstrate ways in which spatial categorisations of the morphological sound shape have remained relatively untouched in academia, despite a co-dependency of frequency, space and time. Theoretical examples and existing visualisations of the sound shape will be considered as a starting point, to determine why the holistic visualisation of space is warranted (Blackburn 2010; Blackburn 2011). A notational system addressing the co-dependency between spatial and spectral sound-shapes will be presented, with reference to its context in Cartesian-coordinate sound environments. This method of electroacoustic notation will incorporate the visualisation of Smalley's categorisation of spatial sound-shapes and ideas of spatial gesture, texture and distribution within Smalley's composed and listening spaces. This visualisation and notation of composed and listening spaces will demonstrate that audio technologies are imperative drivers in the future analysis and understanding of the sound-shape. It will measure the modulation of spatial sound shape properties for Cartesian (height, width, depth) and spherical (azimuth and altitude) across linear temporality, to better represent the complete form of Smalley's sound shape. This spatial notation will aid the rounded visualisation of Smalley's *morphology, motion, texture, gesture, structure* and *form* (Smalley 1986; Smalley 1996; Smalley 1997; Smalley 2014). Use of this notational framework will illustrate ways in which a new tool to score electroacoustic sound-shapes can inform new practices in computer music composition.

1. INTRODUCTION

The visual relationship between *spectral* and *spatial* notation is a fundamental component of spectromorphology. Theoretically they are fused (Smalley 1997; Holbrook 2019; Lotis 2003; 2011), but visually they are often treated separately. While spectral properties of the sound-shape are representative of modern notational influence (see (Blackburn 2010), space is often notated using less linear techniques (Dunkelman 1995, cited in Couprie 2011; Berquin 2011; Harley 1996; 1997; Kim-Boyle 2019), or in a way that strays from the propriety of Smalley's visual sound shape (Boulez in (Merlier 2011; Justel 2011; Anderson 2015). More specifically, the framework of the visual sound-shape has not been re-evaluated to incorporate the precise placement of sound in spherical and Cartesian coordinate settings, which is becoming extremely more relevant as technology propels the granularity of control composers are able to hold in immersive acoustic settings. Without a system in which to accurately notate the coordinates of sound in these spatial settings, the notation of space will always be loose and general.

Smalley considered space imperative in his categorisations. He used the term spatiomorphology to highlight the properties of space in their own right, maintaining that spatial properties were fundamental to sound-shapes and ensuring that these properties constituted their own categorisations of sonic experience (1997: 122). Using sound-shapes to demonstrate that spatial perception is an intrinsic part of spectromorphology, he argued that spectromorphology only existed through the medium of space (1997: 122). As such, Smalley established a terminology that could address the articulation of sound through space and temporality (89-92). These categorisations established a common vocabulary to describe the relationships between spectra- and spatio- structure, growth and behaviour within the temporal flux of electroacoustic music. It is this integrated relationship between space and frequency that has not yet been visually represented in score.

In recent years, researchers have brought the notion of Cartesian spaces to the forefront of discussion (El Raheb et al. 2020; Oomen, Holleman & De Klerk 2016), though further work needs to be done in understanding how to score or notate the spatial properties of co-ordinate environments. Blackburn (2011) addressed how toward the visualisation of space should utilise a "three-dimensional canvas" to present a more accurate picture of spatial sound organisation. Despite this, no visualization currently exists articulating the actuality or degree of such height, width or depth in Cartesian environments, with studies either straying from the notion of Smalley's sound shape visualisation (Ham 2017; Bacon 2022; Carinola & Geoffrey 2022; Merlier 2018), pivoting toward spatial performance (Gorne 2015) or placing an emphasis on static speaker placement and not the notation of sound across space itself Couprie 2005, cited in Couprie 2011; Duchenne 1991; Berezan

2011; Justel 2011; Ellberger et al. 2016). As such, the aim of this journal article is to create an accurate representation of both spectro and spatiomorphological sound shapes in one, cohesive notational system.

Technologies have been increasingly able to accurately map the omnidirectional placement of sound in spatial settings (Berquin 2011; Oomen, Hollemen & De Klerk 2016; El Raheb et al. 2020; Duchenne 2011), justifying the demand for a notational system that accurately scores these spaces. Programs such as 4DSOUND, IRCAM's SISMO, SPARTA, and ZKM's Zirkonium demonstrate how modern computing applications can aid the visualisation of the spatial sound-field. Visually, these programs present the real-time implementations of linear and parametric spatial audio reproduction and processing methods, including the visualisation of and planes to depict the height and width of sound (McCormack and Politis 2019). The next challenge is to convert spatial information into a temporal-based, readable notation to match the dominant time frequency analysis of spectral sound-shapes.

2. SPECTROMORPHOLOGY AND SPATIOMORPHOLOGY

Nystrom (2011) has suggested that acousmatic music is on a trajectory of spatial exploration though discourses of spectromorphology and the space-form. The alignment of spatial propagations to the sound-shape have been largely neglected and the visual relationship between spectral and spatial distribution remains inconsistent. Spatiomorphology is not simply a by-product of spectromorphology, the two are intertwined. Spectra cannot exist without space and spatial aspects must be included to notate spectromorphological processes accurately.

This visual relationship between spectra and space is disjointed and fails to represent the taxonomies they are meant to cooperatively symbolise. In sound-shape notation, the spatiomorphological elements of sound are largely ignored to make way for the linear, frequential sound-shape (see Blackburn 2011). This may well be the consequence of space not being as linear or as pragmatic as the standardised Western score (Mountain 2020), alongside the fact that space is harder to quantify without technological interception. Currently, visualisations of the sound-shape bear resemblance to modern technological representations of spectrality, such as the spectrogram. A main limitation of this spectrogram is its ineffectiveness to capture any spatial detail for analytical or notational purposes. Space itself carries notation into an additional dimension that is often seen as harder to capture, articulate, measure or quantify. Spatial properties of electroacoustic music are consistently scored in non-linear, or abstract scenarios (Harley, 1996; 1997; Kim-Boyle, 2019), with cartesian environments only really being approached holistically as interactive spaces (El Raheb et al., 2020). Newly developed technologies such as the 4D Sound System (Oomen, Holleman & De Klerk 2016) and SPARTA (McCormack and Politis 2019), help bridge the gap in visualising space and demonstrate that sound shapes can now be deconstructed algorithmically, both spatially and spectrally. Despite these technological advancements, visualisations of Smalley's sound shape have not been visualised in a way that ties the measurements of frequency and space together in Cartesian sound environments. As Smalley's categorisation intertwines with space, spatial texture and spatiomorphology, it is imperative to think about how to incorporate space as a medium of score alongside spectral properties. The next challenge is to link the foundations of these studies together, to formulate a notational system that articulates space whilst also including the notion of Smalley's sound shape visualisation.

3. PERSPECTIVAL SPACE

To notate space, a central point is needed to incorporate the spatial properties of morphological sound objects. Though this paper lends example to realised multichannel environments, it can be assumed that the point of origin could be utilised in future studies for binaural settings, to notate the perception of psychoacoustic locality of sound objects through the use of headphones. In cartesian-coordinate sound systems this is created by physical locality (Cross 2019). In stereophonic or headphone-related spaces this could be actualised through depiction of panoramic space, treating the stereophonic properties of left (L) (-90°) and right (R) (+90°) as the minima and maxima of value. Whatever the space composers choose to use, it must be measured or compartmentalised in a way that aligns to the visual parameter, value and scale of frequency. Furthermore, in order represent the parameters of three-dimensional sound-shapes in these omnidirectional Cartesian co-ordinate environments, all three perpendicular axes (x-axis, y-axis, and z-axis) need to be considered. Though the initial spectromorphological rhetoric lends itself to the perspective of the listener, Smalley placed the development of localisation and spatial setting in the hands of the composer (1997: 122). The following proposal of the spatial sound-shape will approach spectro- and spatiomorphology using Cartesian co-ordinates as a simplified starting point for composers and listeners alike. Using Cartesian co-ordinates and a single point of origin (O) to notate the space itself voids any misinterpretation of spatial positioning, spatial movement and scale (Smalley 2007: 56).

4. SCORING SPECTROMORPHOLOGY

To linearise the measurement of spatial sound shapes alongside spectral properties in graphical notation, it is critical to understand what common elements of the frequential sound-shape can be scaled to spatial parameters. When looking at morphological sound shapes and their place in graphical scores, they are depicted linearly. This common approach to spectromorphological notation and its subsequent analysis is reliant on a two-axes representation that neglects the distribution of space, bounding temporality (x) to a frequential or dynamic scale (h) as demonstrated in Figure 1 (Hirst 2011)). Fischman's (Smalley 1997: 227) notation of Crosstalk depicts the common representation of the morphological sound-shape in which time and frequency are bonded together. These visuals do not stray far from early categorisations of the sound-shape, in which frequential distribution flows through a left-to-right temporal approach (Hirst 2011; Blackburn 2011). This frequential sound-shape resembles the linear notation of Western classical traditions, with noticeable influence from spectrographic and technologically aided depictions.

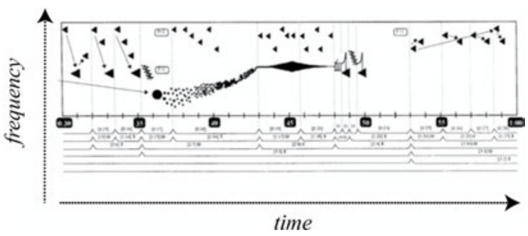


Figure 1. Two-plane system demonstrating frequency and time in a left-to-right approach (Fischman 1997: 227)

Fischmann's Crosstalk is a clear example of this two-plane system, in which time and frequency are bonded in a similar format to the spectrogram, with no consideration of space. This theme is constant, with the frequency/pitch x temporality/time visualisation appearing in various representations of modern electroacoustic sound-shapes. This arrangement of spectral shapes indicates a heavy influence of technological aid. More specifically, these visualisation of morphology as both an analytical and compositional tool (Thoresen 2007; Patton 2007; Nyström 2011; Maestri 2018), align the sound-shape to the familiar visual cues of spectrographic technologies (Mountain 2020: 127). This can be seen in Blackburn's (2011) visual sound-shapes, which form a preliminary foundation of the visual sound-shape. Blackburn (2011) follows this spectra-centric approach, with a horizontal system of time and a vertical approach to predominately frequency-based forms. Blackburn's (2006) visual semblance of the sound-shape aligns to the dominant structure of the spectral or frequential plane, with little consideration the distribution of space (see Blackburn 2006).

By dissecting Blackburn's visual sound-shape, we are left with a simple formula for time frequency analysis. Both parameters of x (time) and h (frequency) are ruled by their respective International System of Units (SI). In electroacoustic settings, both of these units are controlled by the composer as they determine the frequential distribution (Hz) of a sound over time (t). Given that spectral space is defined as the available range of frequency, it can be anticipated that the value of frequency (h) is dependent on the value or range of notes, or of period vibration presented via a top (high frequency) to bottom (low frequency approach). While the frequencies captured in spectrograms vary across the board, the one constant is scale; by way of an upper and lower class limit. Typically, spectrograms hold a frequency scale of 0 to 20000 hertz (Hz). This specific value limit will be used throughout this paper to highlight frequential range. Spectromorphology is very much dependent on how frequencies exist over time and form a conglomerate sound structure (sound-shape) (Lotis 2003: 260). As such, all spatial components or geometries should be scored comparably; though according to the localisation of the sound-shape instead of its frequency. To successfully notate space, the value of frequency in the (time) x h (frequency) equation needs to be replaced by spatial properties as scalable values. Given that all music by nature is temporal (Mountain 2020), the notation of space should exhibit some aspect of space being tied to time or temporality. By replacing the plane of frequency (h) with the spatial planes of width, height and depth, a three-dimensional representation of space can be measured.

5. SCORING SPATIOMORPHOLOGY

One challenge that remains unanswered by previous research is how to notate the value of spatial information in a way that is quantifiable, similar to the measurement of time (seconds) and frequency (hertz) in currently established notational models (Figure 1). Justifications of this notational framework have been drawn on its unique ability to score spatio and spectromorphology with the same notation and measurement models; a method that is missing from previous notations of space and frequency. Using Euclidean or Cartesian geometry to facilitate the work of the composer, we can not only specify the precise positioning of any sound object in three-dimensional space, but also quantify its geometric size, placement and value against that of a spectral shape.

By utilising the model time frequency analysis for time space visualisation, this section will propose a way to notate spatial aspects of electroacoustic music in line with the standardised linear depiction of frequential sound-shapes. By administering a point of origin (O), which is usually the central point of spherical and cartesian spaces (see Figure 3), we can determine the perspectival space of the composer through frontal orientation standardises the central localisation values of the compositional space and match these values to that of the notational score. A listener's own listening space will be dependent on their co-ordinate placement within these acoustic settings and will not necessarily be the same as the compositional space unless they are placed at the point of origin. This can align to the origin (O) of both the spherical and cartesian sound systems. By choosing to utilise a common point (the origin) as the intersectional point for all axes, we are able to treat the compositional space with the same localisation values of the notational space, allowing for precise notation and therefore avoid loose analysis. This origin point is vital to the precision in scoring space that has been missing in previous research. Using these spaces allow for the streamlined analysis of notational values, compositional methods and consequential perceptual effects on the listener from the same data sets. These data sets will be integral to the analysis of perceptual experiences brought about from scoring spatial sound-shapes.

5.1 HORIZONTAL AXIS

To notate the horizontal plane of space, spatial values must be determined. Here, the value of the horizontal axis (x) has been limited to θ = ±100, (Figure 2). Previous instances of this can be seen through Nyström (2011)'s depiction of panoramic space distribution (Smalley 2007: 55; Figure 2). Replacing the plane of frequency (h) with (x) creates the plottable dimensions of the horizontal plane (see Figure 2). When composing for spherical or cartesian co-ordinate systems in this manner, the composer can plot sound-shapes that mimic a combination of movements across horizontal, median and frontal planes that ultimately grant full control of the intricate placement of sound in space.

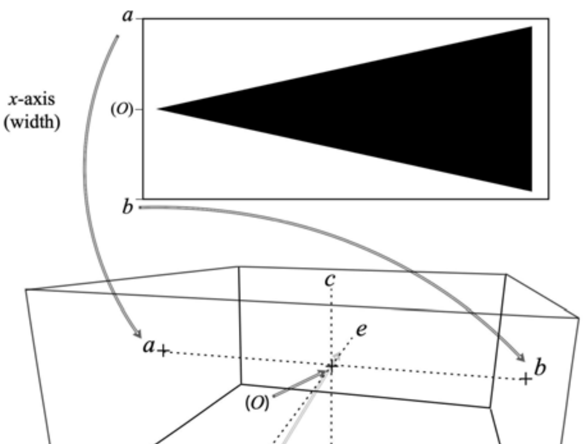


Figure 2. The standard distribution of horizontal space.

Figure 3 depicts the spatial visualisation of emergence, providing clarification on the visualisation of width. This figure depicts the horizontal distribution of the sound-shape in a spatial sense, with Point 1 signifying an onset value of 0. At Point 1, the score indicates that this portion of the sound-shape should bear a thin width, much like that of monophonic playback. Alternatively, the notation of Point 2 is much wider, indicating a gradual increase in horizontal distribution, to the points of a and b, which both represent the furthest possible values from the point of origin (O). Following the sound-shape in the linear fashion of a standardised score, we can see that the resulting sound gradually increases in horizontal occupancy to fill the horizontal spatial plane.

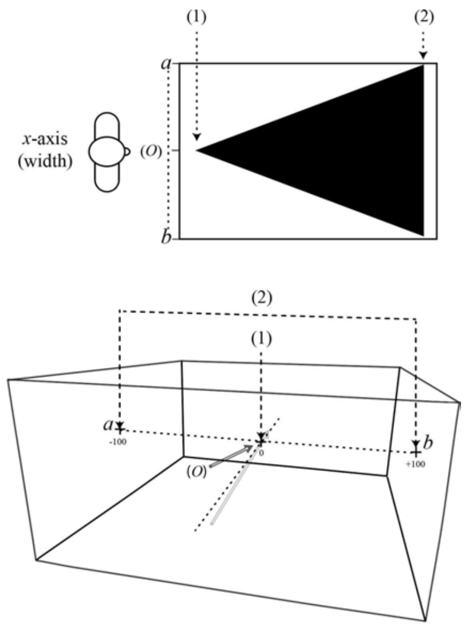


Figure 3. The visualization of emergence of the azimuth plane, indicating sizable spaptial growth.

5.2 MEDIAN PLANE

5.2.1 Analogical Roots

To score the height in Cartesian environments, distinct separations between spatial elevation and misconceptions of frequential height must be drawn. The notion that frequency is tied to spatial perception is analogical and not rooted in factuality. A misapprehension of spatial elevation is often given to higher frequencies (Smalley 1997: 122). In these instances, higher pitches are often perceived as spatially higher, and lower pitches as rooted. In actuality, the frequency of a sound holds no bearing on that sound's spatial location (Smalley 1997: 122) and should be scored as such. In order to notate accurate localisation in topological, geometrical and physical spaces, the composer must break away from the analogy that frequential height impacts space, as often depicted throughout the visualisations of modern mixing systems. In a multichannel setting, elevation or locality can be distinguished by the vertical co-ordinate at which a sound-shape appears in space.

5.2.2 Scoring Elevation and Depth

Like that of the horizontal plane (x), spatial values must be determined in order to notate the vertical plane of space (y). Once again assuming a frontal orientation, the vertical plane of the co-ordinate system highlighted in Figure 2 also depicts the values of c, d, and the spectrum of co-ordinate values between them. Utilising the co-ordinate value system, this time on the y axis of the vertical plane instead of the x axis of the horizontal plane, the composer is given the notational dimensions of an elevation or height. With the same set of lower and upper limits (c, O and d) the composer is able to align the vertical plane (y) to the same visual limits of both frequency (h) and horizon (x).

To score the axis of depth, the above co-ordinate value system can be used to score the ef axis (Figure 2). As such, Figure 4 illustrates the combined graphical staff representation of each spatial and spectral axis, in which frequency, horizontal, vertical and depth are scaled equally alongside one another. When the three staves are scored relative to one another, the accurate notation of three-dimensional space and frequency is achieved. This notational system is aligned to the form of both the conventional, linear score and the established spectral sound-shape. This notational framework forms the basis on which the spatial sound-shape will be notated in conjunction to the frequential sound-shape.

Figure 4. A notational score consisting of frequency, width and height as equal components of the *sound-shape*.

5.3 MOTION

The characteristics of texture, gesture, motion and direction are imperative to the notation of space. Using Blackburn's visual directory of sound units and starts middles and ends (Blackburn 2011), it is apparent that the visual representations of frequency can be applicable to the distribution of sound-shapes spatially. Blackburn's visual cues are transferable to spatial notation, though each notational shape holds different value depending on which plane of the score it resides. An example of this can be seen through the visualisation of ascent (Smalley 1997: 116). On the horizontal plane, the use of ascent symbolism would create new context and indicate a right to left motion (Blackburn 2011: 8), whereas for the median plane the same sound-shape would indicate a low to high movement in localisation (see Figure 5). This can also be seen through Figure 6's visualisation of cyclic motion, in which frequential sound-shapes would need to vary from those of spatial sound-shapes to achieve their respective directional growth.

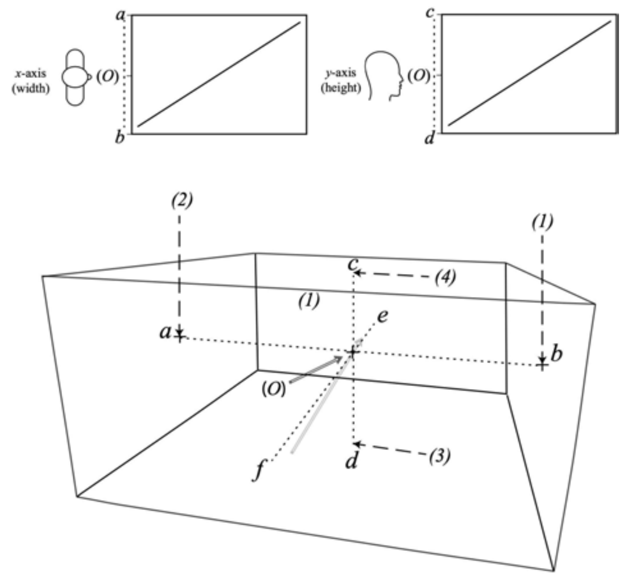


Figure 5. Ascent depicted on the differing axes of elevation and azimuth. Both sound-shapes result in differing motions.

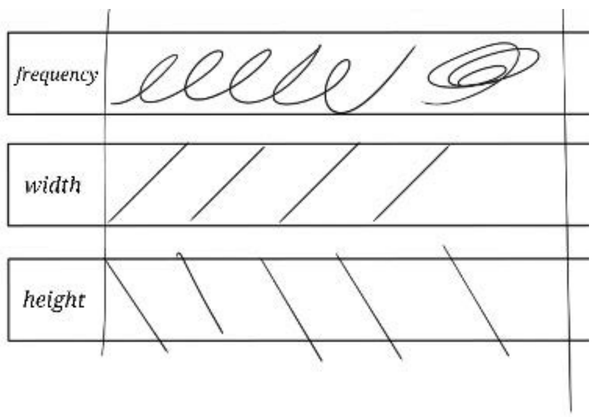


Figure 6. Cyclic motion's various representations (2n spatially).

Blackburn's (2011: 7) application of starts, middles and ends are feasible in terms of notating, or mapping, a spatial phrase or spatial scene. Her visualisation of structural functions, morphological strings and composites can be used interchangeably on spatial cues to notate spatiomorphology. Repurposing Blackburn's (2011) sound-shapes for spatiomorphological notation allows the embellishment of spatial growth and motion processes, formulating new visual meaning. Figure 7 demonstrates how glide (Blackburn 2011:12) can be achieved spatially, distributed over a vertically localised space while Figure 8 demonstrates how dissipation no longer correlates to frequential matter, taking on new meaning by way of spatial location. Using this method, the spatial sound-shape can be notated within the same framework of the spectra and be used in compositional settings to develop complex spatial scenes.

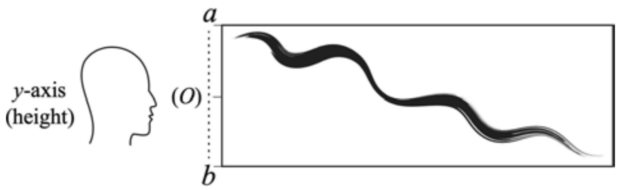


Figure 7. Smalley's *glide* distributed over vertical localized space.

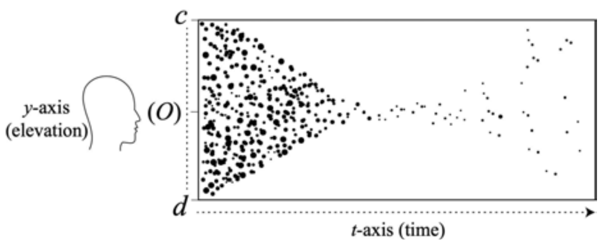


Figure 8. *Dissipation* distributed over vertical localized space.

5.4 COMPOSED AND LISTENING SPACES

One component of *spectromorphology* that has previously been neglected in sound-shape visualisation has been the ability to score, notate or analyse composed and listening spaces accurately. Contiguous spaces, non-contiguous spaces and the manifestations of spatial perspective, or parameters, through time, have remained absent from systems of sound-shape notation (see Blackburn 2011). Without a way to measure or notate spatiomorphology, the composer forfeits the opportunity to measure contiguous space, otherwise known as the properties revealed to the listener through spectromorphological events across space itself (see Figure 9). Without these measurements, any reference point or dimension of the sound space is lost. This also eradicates any reference point to the size, location or depth of any sound that is to be perceived by the listener. As a result, the composer loses the ability to control, or measure, composed and listening spaces in compositional and analytical instances. This means that the composer is only able to visualise a portion of a sound-shape's articulate properties.

This is overcome by scoring the spatial properties of sound-shape. An example of this can be seen through Figure 10, which demonstrates how intimate space can be applied to either elevation or azimuth. By grouping sound objects "closer" to the listener or giving the sensation of appearing to be close to the listener, the composer is able to create spatial intimacy. Alternatively, sounds that appear further away or on the boundary of the listener's audible perception would be out of the intimate space. Similarly, breadth and depth can be notated with sound-shape's size illustrating proportions of breadth, while the distance between a sound shape from the point or origin on the z axis allows for the indication of depth. Both orientation (multidirectional; frontal) and image definition can be visualised using this notation system, depicting the motion, growth, and behaviour of sound in a spatial sense. Using this method composers can begin to accurately define the spatial parameters of unfolding sound shapes and their respective spaces. Through this contiguous space is defined, while trajectorial drama, textural definition and localisation can all be recorded. Figure 10 demonstrates how non-contiguous spaces can be clearly articulated, as sounds are scattered and clustered across regions, highlighting spatial gaps between sound shapes.

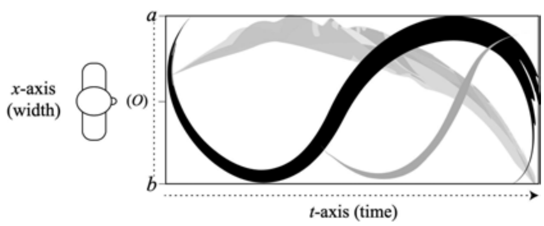


Figure 9. Contiguous space depicting the parameters of spatial distribution.

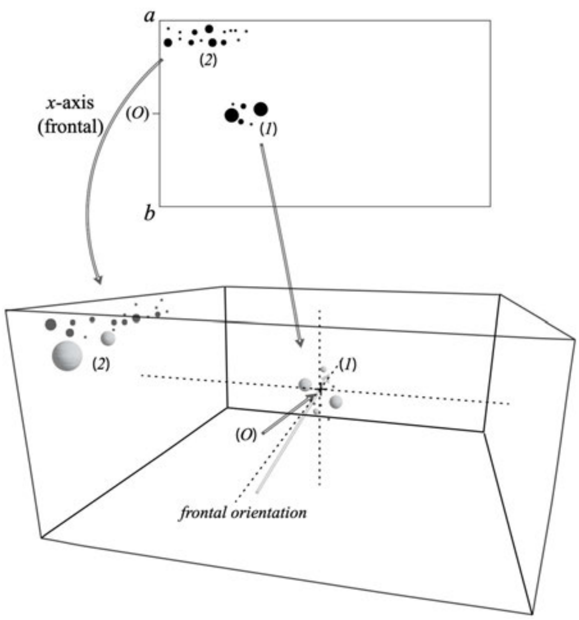


Figure 10. Intimate space.

5.5 GROUPING

Through the notation of spatial properties, Smalley's motion and growth processes are accentuated. By combining all three axes of the sound-shape (frequency, width, height), composers are able to create what I have termed as groupings. Groupings further articulate and heighten the parameters of motion and growth processes. This can be seen through the grouping of spatial and spectral sound-shapes to embellish the 'sense of directed motion' achieved through bi/multidirectional motions. Figure 11 depicts the motions of dilation ('becoming wider or larger') and contraction ('becoming smaller') (1997: 116). The composer is able to notate an embellished sense of dilation (or contraction) by grouping each axes of notation together, with all spatial and spectral qualities morphing in unison to accentuate the proposed motion of widening. The opposite effect of contraction can be achieved through the unison narrowing of each axes sound-shape. Similarly, all cyclic/ centric (Smalley 1997: 116) motions can be notated by mapping out variances to the revolution (or full rotation) of 2π on one or more axes. Reciprocal (Figure 12) and unidirectional motions are also able to be achieved individually, or on multiple grouped axes.

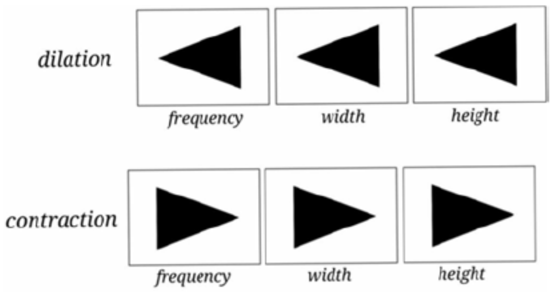


Figure 11. Grouping frequency, width and height together allows for the embellishment of certain *morphological* processes, such as *growth*.

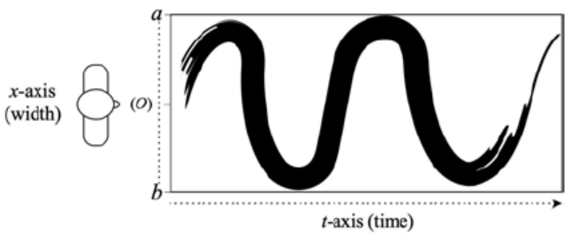
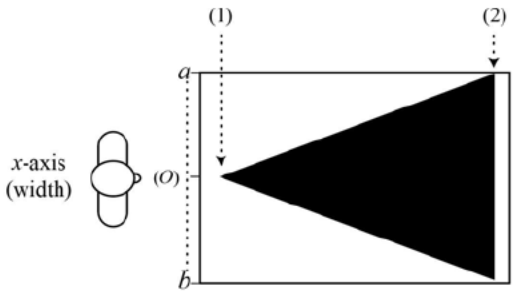


Figure 12. *Reciprocal* space.

6. IMPLEMENTATION

Preliminary implementation of this notational method can be seen through Schema (Cross 2019), a spatial electroacoustic work in which a conjunction of frequential and spatial sound shapes were used as a notational tool. This composition was developed using the 4DSOUND system (Oomen 2016), in which a point of origin (O) allowed for the notation of the Cartesian coordinate system. This composition was diffused across the 48.9 speakers of MONOM's Cartesian co-ordinate multichannel sound system (Figure 13). While developing this notational system, it became clear that spatial sound shapes could be aligned to the typeset of frequential sound shapes and implemented through technological aid. This notation of three- dimensional arrangement allows for the maximum utilisation of cartesian architecture to formulate the controlled spatialisation of unconventional combinations of sound. The spatial properties and resulting listening intricacies of Schema are an example of ways in which to utilise composed and listening spaces with less restraint, through the means of technology. Figure 14 illustrates how the visual relationship between spectral and spatial notation is consistent in scale. The result is a more holistic approach to sound-shape notation. This method of rounded notation has unveiled how interchangeable the categorisations of motion, growth and texture are across the planes of space, frequency and time. By combining frequency, width, and height within the same temporal space, Schema accurately notates the sound shape in a holistic manner that is reflective of both perceptual instinct and precise technological measurement.



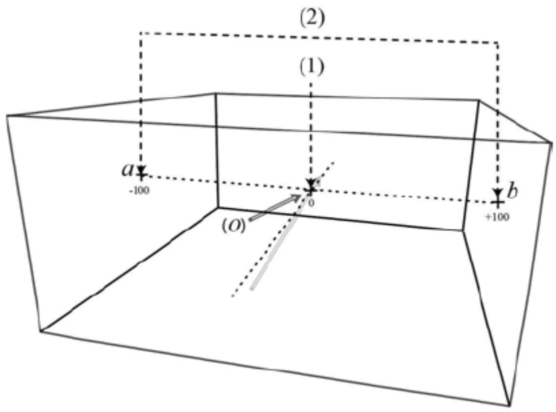


Figure 13. Spatial growth.

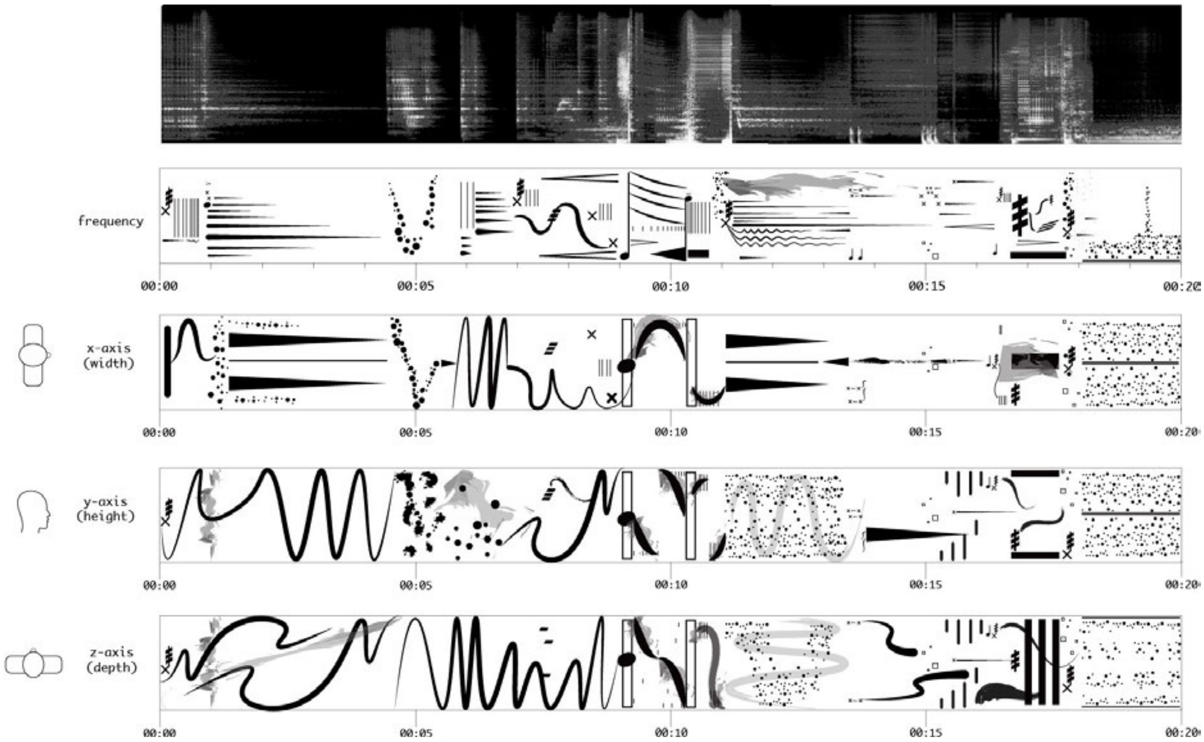


Figure 14. *Schema* (2019) score, utilizing spectral and spatial sound-shapes.

7. TECHNLOGICAL ASSISTANCE

Given that spectromorphological visualisation has leveraged off technological advancement (i.e., the spectrogram), it is important to note ways in which technological advancement might aid the visualisation of the spatial sound shape. In the same way that this paper highlights how interchangeable generic sound-shapes are, it becomes important to capture how the granular placement of textons are just as interchangeable through technological advancement.

Early conceptualisations of the spatial sound shape came with their own sets of technological challenges, pushing any visual representation or notation of spatial sound shapes into the background. Throughout history spectromorphology had largely been intended as a descriptive or analytical tool and not a tool for composition, with Smalley at one stage urging researchers to "ignore technology" (Smalley 1997). It seems restricting to the capability of electroacoustic music when technology is ignored, causing compositional practice to become separated from the sound-shape of perceptual analysis. Today, recent technological advancements enable the measurement and assessment of the sinner properties of the spatial sound-shape in a similar manner to that of frequential spectrograms. The application of vector-based amplitude panning (VBAP), Multiple-Direction Amplitude Panning and High Order Ambisonics have allowed composers to delve deeper into the spatialisation of sound, and inherently sound-shapes (Cross 2018; Zotter and Frank 2019; Holbrook 2019).

Spatial audio and acoustic environments have allowed for the treatment of "space as an instrument with as much a role as previously dominating harmonic constructs" in computer music composition (Cross 2018). Applications such as SPARTA (McCormack and Politis 2019) have since made such technological challenges redundant.

Much like the early traits of spectromorphological sound-shapes that have lent themselves to the visual aids of the spectrogram and sonograph (Blackburn 2006), composers can begin to rely on technological applications such as 4DSOUND and SPARTA as a crutch to understand spatiomorphological sound-shape visualisation. From here, it is important to consider what this technological advancement means for spatiomorphology in compositional, analytical and perceptual settings. With technology that now allow composers to manipulate and measure the inner spatial properties of the sound-shape, next steps in this field of study would benefit from recording the results of perceptual exposure to such manipulated sonic experience. Future research into the precise granular placement and augmentation of texture, gesture and motion would be beneficial in allowing composers to better understand the perceptual response to intricately placed electroacoustic filaments. It is clear that technology is pushing the intricacy of space-form archetypes further. Technology allows electroacoustic composers to delve deeper into the structural fabric of sound, break it down and reconstruct it. As frequential visualisation has surged due to the technological aid of spectrographic information, it becomes important to consider ways in which technology might allow composers to access the inner spatial properties of the sound-shape. Electroacoustic composers and researchers must creatively embrace new technologies to craft new sonic experiences and compositional practices. Technological capability must be welcomed in theoretical settings in order to craft deeper analysis and understanding of the spectromorphological sound shape in electroacoustic composition and resulting perceptual experiences.

8. CONCLUSION

This paper examined Smalley's preliminary taxonomy of the sound-shape and the challenges in linking time, space and frequency in the graphical notation in electroacoustic music. A method to adapt Smalley's sound-shapes for the notation of sound in three-dimensional sound environments was presented. The challenge of spatial accuracy arose, with previous research struggling to capture the precise notational or geometric value of sound objects. The use of a point of origin (O) seemingly resolved this problem in Cartesian environments, allowing the composer to plot sound shapes representative of morphological space, alongside time and frequency simultaneously. This co-ordinate value of space allows spatial information to be measured similarly to the scales of time (seconds) and frequency (hertz). Notationally, the use of groupings have demonstrated ways in which characteristics of sound-shapes can be distributed interchangeably between spectral, spatial and temporal nodes. This paper has demonstrated how Cartesian space can be notated as a starting point for discussion. The next challenge is understanding how to notate perspectival, circumspace or egocentric space around the listener. Future work will address ways in which the bounds of this paper's notational model could be tweaked to score the spherical revolution around the composer or listener. Similarly, future work will investigate how proximate, distal and lateral spaces can be notated in relation to the depth and localisation of sound in reference to the listener's specific vantage point.

Looking forward, it is imperative to consider how the measurement of spatial sound properties can be harnessed to embellish sonic filaments and create further subcategories of spatial sound manipulation. A stronger emphasis on the compositional possibilities and their subsequent analyses is needed to truly understand the parameters of modern sound-shapes. Future research will combine this notational method with the precision of technological and spatially driven sound environments. This research will include the measurement of the above visualisation techniques in compositional settings, and the measurement of consequential listener experiences. I anticipate that this will forge more complex morphological composition and analysis in the field of electroacoustic computer music.

REFERENCES

Anderson, E. L. (2015). Space as a Carrier of Materials, Meaning, and Metaphor in Karlheinz Stockhausen's Music-Theatre Composition Sirius. Bielefeld: transcript Verlag.

Bacon, B. (2022). Rethinking the Notation Design Space. In V. T. a. J. B. a. C. d. P. Santana (ed.) Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'2022. Marseille, France.

Berezan, D. (2011). MANTIS: Festival, Community, Sound Diffusion System and Research. In A. V. Gorne (ed.) LIEN: L'ESPACE DU SON III.

Berquin, L. (2011). SISMO: Solution intégrée pour la spatialisation de sources multiphoniques orientée multipoint. LIEN: L'ESPACE DU SON III: 45-54.

Blackburn, M. (2006). Manuella Blackburn's Valley Flow Analysis. http://orema.dmu.ac.uk/analyses/manuella-blackburns-valley-flow-analysis: De Montfort University.

Blackburn, M. (2010). Composing from spectromorphological vocabulary: proposed application, pedagogy and metadata.

Blackburn, M. (2011). The Visual Sound-Shapes of Spectromorphology: an illustrative guide to composition. Organised Sound : An International Journal of Music Technology 16(1): 5-13.

Couprie, P. (2011). Représenter l'espace? LIEN: L'ESPACE DU SON III: 20-28.

Cross, T. (2018). Paradigm Shifts in the Technological Spatialization of Music. In S. Alexandra, Marco Juan de Dios Cuartas (ed.) Los nuevos métodos de producción y difusión musical de la era post-digital. Seville: Ediciones Egregius.

Cross, T. (2019). Schema: Towards a Post-Biological Composer (2019). Spatial Sound Institute, MONOM and CTM 2019.

Duchenne, J.-M. (1991). Habiter l'espace acousmatique. In F. Dhomont (ed.) LIEN: L'ESPACE DU SON II.

El Raheb, K. S., Marina. Katifori, Akrivi. Ioannidis, Yannis (2020). Symbolising Space: From Notation to Movement Interaction. In R. G. a. G. H. a. J. S. a. A. A. a. J. MacCallum (ed.) Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'20/21. Hamburg, Germany: Hamburg University for Music and Theater.

Carinola, R and Geoffroy, V. (2022). On Notational Spaces in Interactive Music. In V. T. a. J. B. a. C. d. P. Santana (ed.) Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'2022. Marseille, France.

Ellberger, E. (2016). Taxonomy and Notation of Spatialization. In R. H. a. C. N. a. D. Fober (ed.) Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'16. Cambridge, UK: Anglia Ruskin University.s

Gorne, A. v. d. (2015). Space, Sound, and Acousmatic Music: The Heart of the Research. In B. Martha and P. Ralph (eds.) Kompositionen für hörbaren Raum / Compositions for Audible Space. Bielefeld: transcript Verlag.

Ham, J. J. (2017). An architectural approach to 3D spatial drum notation. In H. L. P. a. M. S. a. E. T. a. C. Lage (ed.) Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'17. Coruna, Spain: Universidade da Coruna.

Harley, J. (1996). Iannis Xenakis: La Légende d'Eer and Aïs, Gendy3, Taurhiphanie, Thalleïn. Computer Music Journal 20(2): 124.

Harley, M. (1997). An American in Space: Henry Brant's "Spatial Music". American Music 15(1): 70-92.

Hirst, D. (2011). From Sound Shapes to Space-Form: investigating the relationships between Smalley's writings and works. Organised Sound : An International Journal of Music Technology 16(1): 42-53.

Holbrook, U. A. S. (2019). Sound Objects and Spatial Morphologies. Organised Sound : An International Journal of Music Technology 24(1): 20-29.

Justel, E. (2011). Vers une syntaxe de l'espace. LIEN: L'ESPACE DU SON III.

Kim-Boyle, D. 2019. 3D Notations and the Immersive Score. Leonardo Music Journal 29: 39-41.

Lotis, T. 2003. The creation and projection of ambiophonic and geometrical sonic spaces with reference to Denis Smalley's Base Metals. Organised sound : an international journal of music technology 8(3): 257-267.

Lotis, T. (2011). The Perception Of Illusory And Non-identical Spaces In Acouscmatic Music (v.1). LIEN: L'ESPACE DU SON III: 63-70.

Maestri, E. (2018). A Spectro-Gestural-Morphological Analysis of a Musical-Tactile Score. Tokyo: Springer Japan.

McCormack, L. and Politis, A. (2019). SPARTA & COMPASS: Real-time implementations of linear and parametric spatial audio reproduction and processing methods.

Merlier, B. (2018). Space Notation in Electroacoustic Music: From Gestures to Signs. In S. B. a. J. Bresson (ed.) Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'18. Concordia University.

Merlier, B. P., Hélène 2011. Thélème contemporain et L'ESPACE du son dans la musique électroacoustique la 5ème dimension du son musical. LIEN: L'ESPACE DU SON III: 29-38.

Nyström, E. 2011. Textons and the Propagation of Space in Acousmatic Music. Organised Sound : An International Journal of Music Technology 16(1): 14-26.

Oomen, P. H., Poul. De Klerk, Leo. 2016. 4DSOUND: A New Approach to Spatial Sound Reproduction and Synthesis: Spatial Sound Institute. LIVING ARCHITECTURE SYSTEMS GROUP (WHITE PAPERS 2016).

Patton, K. 2007. Morphological notation for interactive electroacoustic music. Organised sound : an international journal of music technology 12(2): 123-128.

Smalley, D. (1986). Spectro-morphology and Structuring Processes. In S. Emmerson (ed.) The Language Electroacoustic Music. London: Palgrave Macmillan UK.

Smalley, D. 1996. The listening imagination: Listening in the electroacoustic era. Contemporary Music Review 13(2): 77-107. Smalley, D. 1997. Spectromorphology: Explaining Sound-
Shapes. Organised Sound : An International Journal of Music Technology 2(2): 107-126.

Smalley, D. (2014). Spatiality in acousmatic music. CIRMMT Distinguished Lectures in the Science and Technology of Music. [Video file].

Thoresen, L. 2007. Spectromorphological Analysis of Sound Objects: An Adaptation of Pierre Schaeffer's Typomorphology. Organised Sound 12(2): 129-141.

Zotter, F. and Frank, M. (2019). Ambisonics: A Practical 3D Audio Theory for Recording, Studio Production, Sound Reinforcement, and Virtual Reality. Cham: Springer International Publishing AG.

CHAPTER FOUR

Complexities of Spatial, Temporal and Amplitude Morphologies

4.1 Introduction

Building upon the knowledge gained in Chapter 3, Chapter 4 shifts the focus toward an investigation of temporal and amplitude complexities in electroacoustic music composition. By examining these dimensions, a deeper understanding can be achieved regarding how compositional choices influence the emotional impact, aesthetic engagement, and overall quality of electroacoustic music.

In this chapter, an exploration is made into the intricate relationship between temporal complexities, such as rhythm, tempo, and duration, and their perceptual effects on listeners. By studying the cognitive and psychological mechanisms involved in processing temporal information in music, insights can be gained into how composers can manipulate these elements to create tension, release, and narrative flow within electroacoustic compositions. Furthermore, patterns of amplitudinal structure and complexity are analysed, covering aspects such as dynamics, loudness, and the spatial distribution of sound intensity. Understanding the interplay between amplitude variations and listener perception enables the crafting of electroacoustic compositions that evoke spatial immersion, dramatic contrasts, and intricate sonic textures.

By shifting the focus from spectral and spatial complexities to temporal and amplitude dimensions, Chapter 3 expands the understanding of the multifaceted nature of electroacoustic music composition. This exploration contributes to a comprehensive framework for designing and manipulating sonic materials, allowing composers to harness the full potential of these dimensions to create captivating and emotionally resonant musical experiences. Through an analysis of existing research and case studies, this chapter aims to provide valuable insights and practical guidelines for composers seeking to navigate the intricate interplay between temporal, amplitudinal, spectral, and spatial complexities in their electroacoustic compositions. The same set of auditory stimuli were employed in Paper 2 as were used in Paper 1, however, the papers diverged in their investigative focus. Paper 1 concentrated on spectral complexity, studying how variations in spectral content influenced listener perceptions. Paper 2 expanded the investigation to include amplitude, spatial, and temporal complexities, using the same group of participants and stimuli. This approach ensured a more thorough exploration into morphological impact. The stimuli used in Paper 2 can be found in Appendix B.

PAPER 2

Cross, T. (in review b). Analysing the acoustic, perceptual and morphological correlations of spatial, temporal and amplitude complexity in electroacoustic stimuli, *Music and Science*.

Routledge
Taylor & Francis Group

Time Series Analyses of Subjective Perceptual Responses to Variable Spectromorphological Complexity in Electroacoustic Stimuli (in review)

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Abstract

Smalley's spectromorphological taxonomy is critical to the creation of electroacoustic music. The challenge is to understand how the spectromorphological properties of electroacoustic stimuli impact listener perception, preference and understanding. The aim of this study is to investigate how varying complexities of spectral structure in electroacoustic stimuli impact listener experience in modern musical environments. Ninety electroacoustic stimuli were created and measured based on the common components of complexity found in Smalley's spectromorphological sound-shape (Smalley 1986; Smalley 1996; Smalley 1997). Spectral gesture and motion were evaluated through autocorrelation (Geake, 1997), acoustic richness (AR), dominant frequencies, feature-based flux, spectral flux, continuous spectral entropy, spectral entropy and zero crossing. Spectral structure (including spectral texture) was determined through frequential range detection, spectrographic intricacy, spectral flatness, spectral texture and spectral definition within various frequential banding. Twenty-three participants heard 45 pairs of stimuli and indicated their preference, presumed complexity, presumed completeness and level of interest and responses were compared to spectromorphological gestures and structures. Time series analyses tested the hypotheses that spectral and acoustic complexities influence listener preference, interest and assumptions in electroacoustic settings. Results indicated that spectral structure and modulation affected listener responses, with particular spectral gestures producing higher rates of influence than spectral structure. Higher levels of spectral complexity correlated to higher clearances of preference and interest. The structural composition of a sound influenced listeners' assumptions of complexity and completeness relating to a sound. Listeners agreed that sounds with larger spectral gesture and structure sounded more complete.

1. Introduction

Smalley's morphological context is critical to the discourse of electroacoustic music. While existing perceptual studies of spectral properties analyse specific instruments (Lloyd et al., 2018), non-spectromorphological contexts (Bailes & Dean 2007a, 2007b, 2009), longer musical pieces (Kamalzadeh et al., 2016; Bailes & Dean, 2012) or overall pitch and rhythm structures (Honingh et al., 2015). little is known about how the spectromorphological ties of electroacoustic stimuli directly impact listener perception, preference understanding and satisfaction. The challenge is to identify the links between varied spectromorphological structures and their effect on listener understanding and preference. This paper explores what influence acoustic features have on listener perception in a spectromorphological context, and if the varying complexities of spectral morphology may impact experience in the same way as neurological events (Bardy et al., 2015).

Connecting models of spectromorphology (Smalley 1996; 1997) to that of modern acoustic analysis (Bailes & Dean, 2007a, 2007b, 2012) and listener experience (Kuriki et al., 2007; Tremblay 2007) is complex. Cross (in press) determined that higher rates of spectral structure and spectral gesture result in higher rates of morphological complexity (see also Donderi, 2006; Durmus, 2020; Nyström, 2011). Using this model (Cross, in press) of morphological context (Figure 1), measures of spectromorphology were then matched to common corresponding signal processing measures in modern acoustics, bioacoustics and signal processing analysis (see Figure 1), much like the objective measurements taken to define complex sound forms (see Smit et al. 2019; Burns & Rajan, 2019; Singh, 2011).

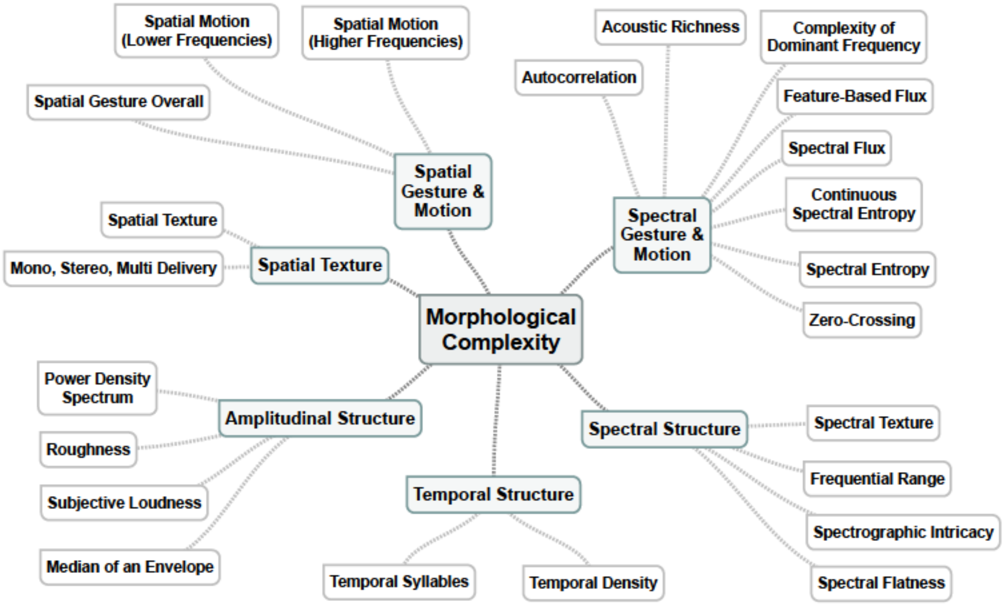

Figure 1. Bridging morphology with corresponding acoustic and signal processing measures

At the nexus of neurological sciences and music cognition, technology has altered our experience of Schaeffer's (Schaeffer et al., 2017) acoustic reality (Stenslie, 2006; Wang, 2013; Cross, 2018) and the brain's adjustment to acoustic cues (Cruces-Solís et al., 2018). Studies have determined that when the acoustic properties of sound are manipulated to contain more harmonic information, this increase of spectral complexity forces higher neurological responses (Kuriki et al., 2007; Tremblay 2007; Tervaniemi et al., 2000), impacted by pitch, timbre and timing (Kraus et al., 2009, Gingras et al., 2013). Sounds with higher rates harmonic information have stimulated enhanced neural responses in their listeners when compared their 'pure' counterparts (Shahin et al., 2005; 2007; Bardy et al., 2015). It can be assumed that neurological change to acoustic morphology would raise similar trends in perceptual experience, in the same way that neurology and cognitive fields of research interlink. Despite these assumptions, there is little research into how the discrete spectral components of stimuli might impact a listener's perceptual preference, interest or assumption of sonic experience, making this study pivotal in furthering perceptual understanding in technologically led musical environments.

Most quantitative research focuses on stimuli in a general sense, without specifying the temporal, spatial or spectral capabilities of digital output (see Smit et al., 2019). Isolated perceptual preference and contrast effect tests have shown that acoustic complexity has the capacity to shape listener 'arousal' (Bailes & Dean, 2012), preference (Lloyd et al., 2018, Smit et al. 2022) and emotional response (Juslin & Vastfjall 2008) to musical stimuli, though little research exists on the associations between spectromorphology and cognition. Similarly, most research has been limited to the acoustic properties of spectral entropy, roughness, flux and flatness. As a result, there has been little attention to the granular effects of technical or computer-based modulation on acoustic stimuli in composition. This study is timely, and will investigate spectromorphological complexity and positive listener preference, (after Cross' congruent model (Figure 1)). Using the work of Bailes & Dean (2009, 2012; Smit 2022) research as a starting point, this paper will look at previously unacknowledged acoustic properties, assessing the impacts of autocorrelation, acoustic richness, complexi dominant frequencies and frequential ranging. It will test how participants respond to computer-generated sounds in succession to one another (after Norman-Haignere et al., 2015) to identify how various morphological properties is required to clearly exhibit and track trends and differences in perceptual responses of large cohorts. Once the paradigms of sound are better understood, these inferences can be applied to the practices of complex computer-generated music composition. The first hypothesis of this study is that the spectral complexity (both structural and modulational) in electroacoustic stimuli impacts a listener's preference and level of interest. From here, the second hypothesis of this study is that higher levels of acoustic complexity correlate to higher clearances of preference and interest. Technology has created new modes of listening and understanding sounds in the world around us (Thoresen, 2007); Schaeffer 2017; Gomez-Marin et al., 2014), this study will also aim to discover how these spectral properties of a sound might impact a listener's perceptual judgement of perceived complexity (hypothesis three) and completeness (hypothesis four).

Method

Participants

Participants (n = 23; age range = 22-49; median = 34) with varying proficiency of computer music undertook this study. Twelve (52%) participants self-identified as being "proficient in computer music theory and/or composition", while eleven (48%) identified as having no proficiency in this area. All twenty-three participants identified as having no known hearing impairments. Nine (39%) participants completed the test using "high quality / professional headphones", with fourteen (61%) using low quality or everyday headphones. Both options were preferred to listening with no headphones, which zero (0%) participants utilised. All participants self-identified their level of musical ability in theory, composition and performance. The results ranged from a "high level of musical ability" (26%), "above average musical ability" (18%), "average musical ability" (35%) and "very little musical ability" (21%). As previous studies have indicated that sex and/or gender does not play a particular impact on these types of perceptual studies (Durmus, 2020), these demographical pieces of information were disregarded from the study and subsequent analysis.

Stimuli

Ninety electroacoustic stimuli were analysed and based upon common components of morphological complexity. The duration of sounds ranged from 0.51 seconds to 5.98 seconds in duration. The average duration of all sounds was 3.24 seconds. The structural fabric of these sounds built upon the idea of Smalley's spectro- and spatiomorphological sound-shapes (Smalley, 1986, 1996, 1997). These stimuli varied in quantifiable characteristics but all structural components that were easily linked to Smalley's morphological grouping in some way. These connections were combinations of spatial and spectral structure, spatial and spectral gesture, amplitude modulation, and temporal structure. 3036 responses were accumulated over a series of perceptual tests, in which listeners provided subjective responses against each stimuli in terms of preference, presumed complexity, presumed completeness and listener's level of interest. These responses were combined in a robust dataset. This dataset was heavily analysed using common statistical methods to reveal key trends in the cohort's preference of electroacoustic structure and trends in spatio and spectro sound cues. The results of these subjective perceptual assessments are presented in this study.

Acoustic Analysis

MATLAB (MATLAB, 2022), R (Team, 2022) and PRAAT (Boersma, 2022) were utilised to analyse the structure and complexity of each sound's spectral complexity, based upon the acoustic properties outlined in Figure 1. Sounds were measured and assessed on their complexity based upon the levels of information each query returned. Stimuli comprising higher rates of spectral information were deemed more complex in their subsequent categories for this study, aligning with comparable studies (Donderi, 2006; Durmus, 2020; Nyström, 2011). Spectral gesture and motion were measured through the processing of autocorrelation (Geake, 1997), the measurement of acoustic richness (AR), the complexity of each stimuli's dominant frequency (dfreq), feature-based flux, spectral flux, continuous spectral entropy, spectral entropy and zero crossing (zc). Spectral Structure (including spectral texture) was measured through the return of frequential range detection, spectrographic intricacy, spectral flatness, spectral texture and spectral definition within various frequential banding.

A second analysis determined the strength of relationship between stimuli composition and listener response against each acoustic property (Pearson coefficient correlation models). This analysis tested each hypothesis that certain spectral complexities influence a listener's response in terms of preference, presumed complexity, presumed completeness and level of interest more than others. The interactions between stimuli properties (fixed, continuous variables) listener's responses to respective stimuli (dependent, discrete variables) determined the level of effect ((Dobrowohl et al., 2019; Pearce and Müllensiefen, 2017; Lloyd et al., 2018; Juslin & Laukka, 2004; Tervaniemi et al., 2000). Perceptual tests returned positive (+1) and negative (-1) values, based upon a listener's choice of stimuli regarding preferability, interest and assumption of each stimuli. These scores were analysed across an individual, and the cohort in order to identify overall trends of listener response. The support of Eta squared readings (ANOVA model) Streamlined percentages of variance were accounted for with supplementary model testing (ANOVA, Eta squared) (Levine & Hullett, 2002; Kamalzadeh et al., 2016), while statistical significance was assessed across all models (Pearson Chi Squared).

Procedure

Listening sessions lasted approximately fifteen minutes in total, and due to COVID-19 restrictions, took place virtually using REDCap, a browser-based, metadata-driven online survey application for managing online surveys. The study was conducted in English, and participants were asked to listen to a series of 90 two-second musical cues and fill out an adjoining questionnaire describing their preferences, selectivity and understanding of which of the paired cues sounded more complex, interesting and complete. These cues were played in no particular order, as to not skew results. Each of the ninety stimuli were presented to participants in pairings alongside another sound of similar spectral property. Within each pairing, each sound was randomly ordered, then labelled Sound A or Sound B. Listeners were asked to indicate their preference, interest, and comprehension of each sound's complexity. For each pairing, participants were instructed to play, and replay, both Sound A and Sound B as they answered the following four questions:

(1) Which audio sample do you prefer?

(2) Which audio sample do you find to sound more complex?

(3) Which audio sample do you find more interesting?

(4) Which audio sample do you find sounds more complete?

Data Analysis

Spectral Gesture

The overarching category of spectral gesture comprised of autocorrelation, acoustic richness, complex dominant frequency, feature-based flux, spectral flux, continuous spectral entropy, non-continuous spectral entropy and zero crossing. The harmonic complexity of each stimuli's fundamental frequency (autocorrelation) was measured by using short-term autocorrelation queries of time waves (autoc) within the seewave package of R (Sueur et al., 2008). The return of each object's stereophonic autocorrelation was averaged to achieve an overall reading for each stimuli. To clean the data, sounds were assessed against an amplitude threshold of 10% (autoc(x, threshold = 10)). The feature-based flux of each stimuli was analysed using open-source library soundgen's analyze (Anikin, 2019), in which the rate of change in acoustic features (such as pitch and HNR) were generated and measured. The return of each object's stereophonic channels was averaged to achieve an overall reading for each stimuli. To cross-analyse the results of stimuli autocorrelation (autoc), the dominant frequency of each time wave was measured utilising dfreq (Sueur et al., 2008). The return of each object channel's corresponding frequency of highest amplitude was averaged to achieve an overall reading for each stimuli. The cross-comparison of each pairing's Acoustic Richness was computed using seewave's AR (Sueur et al., 2008). Utilising this package's acoustic index allowed for the combined ranking of the and the entropy of each sound's temporal envelope (Ht) and amplitude envelope median (M) indices respectively, returning a ranking of which sound was made up of a more intricate fabric.

Each sound was assessed within its original pair, for example a snare drum recording (stimuli 7) was ranked against its augmented variant (stimuli 8). All ninety stimuli were measured, though this section of the study disregarded eleven pairings due to their similarity in acoustic structure. For this section of the study, 11 pairings were discounted as their main points of difference were not spectral, and mainly spatial. Continuous spectral entropy was measured using seewave package's csh function, to quantify the information fluctuation complexity of each stimuli's frequential unpredictability (x) across temporality (y) (see Figure 2). Sounds were measured to see which of the pairing held more overall spectral fluctuation. Sounds were also assessed against their periods of low or null entropy. Sounds with higher periods of NULL entropy or deviation were deemed less complex. Statistically, sounds that were considered to sound less complex were also considered less preferred, less complex and less interesting. Shannon and Renyi entropy of each frequency spectrum was also computed, gauging similar indications of spectral analysis obtained through 'spec' or 'meanspec'. Like studies in sound structure recognition, zero-crossing was used to measure the instantaneous frequency (y) of a time wave (x) by zero-crossing variable oscillating cycles. zc queries were executed within the seewave package of R with an amplitude threshold argument (threshold = 25) to focus the analysis on dominant frequencies.

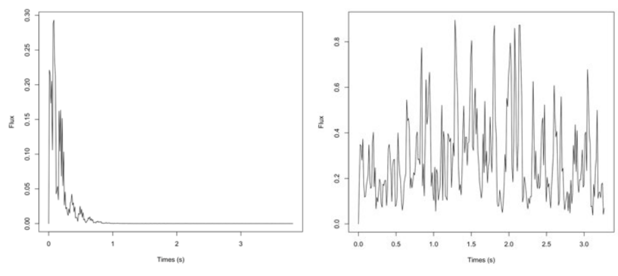

Figure 2 The visual representation of spectral flux (F). Less visual convolution correlates to low levels of spectral flux, as seen in a. b depicts a large amount of visual fluctuation, representing higher spectral flux (F).

Spectral Gesture

The category of spectral structure comprised of frequential range, spectrographic intricacy, spectral flatness and spectral texture. The intricacy of spectrogram was measured using MATLAB and Avisoft-SASLab Pro, in which automatic parameter measurements of spectral threshold, motion, interactivity and bioacoustics tracking were performed. Freq_range_detec and auto_detec queries executed within the WarbleR package (Araya-Salas & Smith-Vidaurre, 2017) of R detected the frequential range(s) of each stimuli's acoustic signal. Each query utilised an amplitude threshold argument (dB. threshold = 48) to focus the analysis on dominant frequencies. Bottom frequencies ranged from 12 Hz to 459 Hz, with an average lowest frequency of stimuli was 33.56 Hz. Pearson's correlation coefficient analysis was used against lower frequencies and listener preference, indicating that higher rates of preference ($\eta2$ = .329) were attributed to sounds that held lower bottom frequencies. The equivalent analysis was performed on each sound's highest frequency. Highest frequencies ranged from 621 Hz to 24,000 Hz, with an average highest frequency of stimuli was 14354 Hz. The tonality coefficient (spectral flatness) measure of each stimuli was measured using R's seewave sound analysis package, in which the geometric mean of the power spectrum was divided by the arithmetic mean of the power spectrum (sfm(spec)). Single values between 0 and 1 were returned, determining the measure of signal pureness/ noisiness.

Results

Spectral Structure

The overall dataset indicated that sounds with the lowest harmonic frequency of the pairing had higher chances of being the preferred sound. This is confirmed by the 96% of listener responses deeming the lowest (or matched lowest frequency) belonging to their preferred sound. Similarly, 90% of listeners deemed stimuli with the lowest frequency of the to be more complex, 89% more interesting and 86% more complete. The average of these readings demonstrated that 93% of sounds with lower frequencies were considered more preferred, complex, interesting and complex than their frequentially thinner pairing. Sounds containing higher upper frequencies held a lower means of association for preference ($\eta2$ = .31) but held a consistently strong coefficient ($\eta2$ = .33) for complexity (see Table 1). Only 67% of listeners saw the highest frequency belonging to the preferred sound, which equated to roughly 25% weaker than the performance of lower frequencies. Despite a Means of Association of ($\eta2$ = .31), this result was well below the impact of bottom frequencies. Similarly, 68% of listeners considered these sounds more interesting, with presumed completeness achieving a 66% consensus rate on sounds with lower bottom frequencies.

Seventy percent of listeners saw the highest frequency as belonging to the preferred sound. The average frequency range of more complex stimuli was 15.69 kHz, while the average frequency range of less complex sounds was 20% lower, at 12.68 kHz. Seventy-two percent of responses indicated that sounds with a higher top were considered by listeners to be more complex. Approximately 73% of sounds with higher frequency ranges were deemed to be more preferred, interesting, complete and/or complex. Much like that of autocorrelation, higher rates of preference ($\eta2$ = .77), complexity ($\eta2$ = .78), level of interest ($\eta2$ = .65) and completeness ($\eta2$ = .74) were attributed to the sound in each pairing that held higher spectral intricacy. Homogeneity tests indicated that these findings were also statistically significant ($p = < .001$). The study saw an overall average of 97% of sounds with highest spectrogram intricacy being deemed more preferred,

	Preference (*r*)	**Complexity (*r*)**	**Interest (*r*)**	**Completeness (*r*)**	**Averages (*r*)**	**Effect Size**
Lower Frequencies	-.49**	-.54**	-.53**	-.50**	-.51**	**High**
Higher Frequencies	.31**	.33**	.31**	.29**	.31**	Med
Frequential Range	.32**	.33**	.33**	.30**	.32**	Med
Spectrographic Intricacy	**.77****	**.78****	**.65****	**.74****	**.73****	**High**
Spectral Flatness	.48**	.47**	.47**	.47**	.47**	Med

**. Correlation is significant at the 0.01 level (1-tailed).

Table 1. Pearson Correlation Coefficient of Spectral Structure

interesting, complete and/or complex then their less spectrally intricate counterparts.

Sounds with less spectral flatness were indeed attributable to the preference, presumed complexity, presumed level of interest and presumed completeness of electroacoustic samples, hovering between 27% ($\eta2 = .47$) (presumed level of complexity) and 34% ($\eta2 = .48$) (preference). As an extension of the findings of Bailes & Dean (2016), this study found that 70% saw the least spectral flatness of the two belonging to the sound that was considered by listeners to be more complex. 70% saw the least spectral flatness of the two belonging to the sound that was considered by listeners to be more "interesting". Likewise, 68% saw the least spectral flatness of the two belonging to the sound that was considered by listeners to be more "complete".

Spectral Gesture

Table 2 summarises the Means of Association found across all 3036 response profiles for autocorrelation, spectral intricacy, complexity of dominant frequencies (dfreq), acoustic richness and frequential range against listener preference, level of interest, assumed complexity and assumed completeness.

Autocorrelation was linked to preference ($\eta2 = .77$), complexity ($\eta2 = .76$), level of interest ($\eta2 = .77$) and completeness ($\eta2 = .76$) (ANOVA ($p = < .001$)), with 95% of listeners favouring sounds with higher rates of autoc. Ninety-seven percent of pairings saw the stimuli with higher harmonic complexity of the fundamental frequency belonging to the sound that considered to be more preferred, complex, interesting, and complete. Dominant frequencies (dfreq) recorded lower coefficients than autocorrelation in all four categories, with preference ($\eta2 = .72$), complexity ($\eta2 = .71$), level of interest ($\eta2 = .74$) and completeness ($\eta2 = .71$) being attributed to the complexity of frequencies that were highest amplitudinally. Ninety percent of stimuli with the more complex dominant was considered by listeners to be more preferred and more complex (ANOVA, χ^2 (2, N = 90) = 69.66, $p < .001$)).

Acoustic Richness correlations ranged between presumed complexity ($\eta2 = .59$) to preference ($\eta2 = .57$), demonstrating that Acoustic Richness influenced subjective preference, though not to the same levels of autocorrelation ($\eta2 = .77$). Despite this, 91% of listeners subconsciously found stimuli with higher Acoustic Richness as more complex. Weaker correlation was found between Feature Based Flux, hovering between ($\eta2 = .34$ (presumed complexity)) to ($\eta2 = .40$ (presumed completeness) (ANOVA χ^2(11, N = 90) 12.39, $p = < .001$). Spectral flux held medium-sized correlations, holding attributions between level of interest ($\eta2 = .29$) and presumed complexity ($\eta2 = .33$). Only 63% of listeners tagged the stimuli with the higher spectral flux as their more preferred sound.

Continuous spectral entropy (csh) drew strong links to preference ($\eta2 = .64$), complexity ($\eta2 = .67$), level of interest ($\eta2 = .66$) and completeness ($\eta2 = .64$), with 89% of listeners favouring sounds with higher rates of csh. On the spectrum of pure tone (0) to pure noise (1), the average csh value of preferred sounds was 0.79, with the average value of non-preferred sounds sitting at 0.66. Comparing sounds with a spectral entropy value difference of (SE) = >0.10, sounds that were assumed to be more complex held an average of 53% more continuous spectral entropy values than non-complex sounds, indicating that listeners associate complexity with sounds that contain higher levels of fluctuating noise in comparison to simply pure tones. Listener preference ran similar results, with sounds that were deemed more preferably holding 48% more continuous spectral entropy than less-preferred sounds. Low rates of preference ($\eta2 = .26$), complexity ($\eta2 = .29$), level of interest ($\eta2 = .28$) and completeness ($\eta2 = .25$) were attributed to continuous spectral entropy (csh) (ANOVA χ^2 (16, N = 90) 23.15, $p = < .001$), with 92% of listeners favouring sounds with higher rates of csh across all four hypotheses. This correlates with the findings of

	Preference (*r*)	**Complexity (*r*)**	**Interest (*r*)**	**Completeness (*r*)**	**Averages (*r*)**	**Effect Size**
Autocorrelation	0.77	0.76	0.77	0.76	0.77	High
Acoustic Richness	0.57	0.59	0.60	0.57	0.58	High
dfreq	0.72	0.71	0.74	0.71	0.72	High
Feature-Based Flux	0.38	0.34	0.36	0.40	0.37	Med
Spectral Flux Average	0.31	0.33	0.29	0.32	0.31	Low
Continuous Spectral Entropy	0.64	0.67	0.66	0.64	0.65	High
Zero Crossing of Time	0.63	0.64	0.64	0.62	0.64	High
Spectral Entropy	0.27	0.29	0.28	0.25	0.27	Low

**. Correlation is significant at the 0.01 level (1-tailed).

Table 2. Pearson Correlation Coefficient of Spectral Gesture

autocorrelation, in which spectrally busier signals outperformed spectrally weaker (or less complex signals) in terms of listener preference and identification. Ninety percent of stimuli with higher rates of zero-crossing were more preferred by listeners. Assumed complexity (95%), interest (93%) and assumed completeness (90%) also performed highly.

Totals

Across all sounds, 98% of individuals were in agreeance that one sound was more complex than its pair, with 96% finding choosing a consensus sound as more interesting and 93% choosing the more acoustically complex sound as more complete. Despite some stimuli pairings having an extremely minute nuance between them, the majority of listeners (93%), regardless of age or musical talent, showed a clear, agreed preference of one sound overall. The variance inflation factor (VIF) hovered between 1.135 (spatial gesture) and 1.391 (spectral structure), indicating that multiple linear regression outputs would be likely reliable. The measure of association tests were only valid when comparing all 90 sounds and their preferences as opposed to strictly measuring preferred sounds. An overall Pearson Chi-Square tests showed that the differences among the categories of more preferred, more complex, more interesting and more complete were significant ($p < .001$). Overall variance in assumed complexity was highly attributed to higher levels of spectral gesture ($\eta 2 = .54$) and spectral structure ($\eta 2 = .49$). A listener's preference toward sounds with more spectral gesture resulted in a majority consensus of 81 %. Fleiss kappa measurements (Fleiss, 1971), determined that the degree of actual agreement between complexity and level of interest equated to ($\kappa = .553$, $p < 0.01$). Little delineation was found between musically inclined participants ($p = .0003$, $F = 3.12$) and non-musically inclined participants (p value is $p = .001$, $F = 1.94$) who answered all 180 questions. From this pool, multicollinearity occurred between the independent variables of spectral gesture and complexity.

Statistical Anomolies

Stimuli with high levels of noise and low levels of harmonic signal were less preferred, despite being more complex acoustically. This anomaly was recurrent throughout the study, with the use of harmonic-to-noise (HNR) ratios confirming sounds with higher returns were less preferred. Similarly a pairing of C3 tones with and without added noise drew anomalies amongst listeners. The only difference between these sounds was that one sound had 22% more noise than harmony than the other. Despite being technically more complex in almost all attributes, the sound without added noise was still the preferred sound 27% of the time. Other HNR-related anomalies developed where both sounds in a pairing contained roughly three times as much noise as the study's average, in which the less complex sound with less noise was preferred. Based upon these anomalies, it is assumed that this is the case because the HNR ratio of sound 1b is too high, with listeners only appreciating HNR levels to a particular threshold before it appears to be unintelligible noise. Simply put, when the harmonicity sounds begins to get lost, sounds appear to become less desirable. This indicates that there is a threshold between harmony and noise in which once the harmony is masked by too much noise, it becomes less desirable.

Discussion

This study was concerned with the impacts that spectral complexity plays on listener preference, experience and understanding. All four hypotheses were supported from the findings, with results indicating that both spectral structure and spectral flatness impact listener preference and experience. In support of hypothesis one, results indicated that listener preference was heavily impacted by the complexity of a sound's spectral gesture. This is consistent with the related findings of Bailes & Dean (2012) and Lloyd et al. (2018), who found that acoustic complexity had capacity to shape listener arousal and preference respectively. Autocorrelation, Acoustic Richness, Complex Dominant Frequency, Continuous Spectral Entropy and Zero Crossing returned high effect sizes. In contrast, Feature-Based Flux, Spectral Flux and Spectral Entropy all returned low, but existent association. Sounds that were considered more complex had a higher chance of holding a larger frequential range, low frequency, low spectral flatness and high spectral entropy. Building on their findings, this study's deeper analysis of acoustic properties categorised by spectromorphological structure indicated that spectral gesture held a higher impact than that of spectral structure. Findings also indicated that sounds with more harmonic information are more likely to be considered by musicians and non-musicians as more preferred and complex. These results align with previous studies that have indicated higher frequential ranges produce more harmonic information in stimuli, while also containing more clarity (Bardy et al., 2015). The results of this study are vital as they offer a spectromorphological context to previous findings.

In support of hypothesis two, higher levels of spectral complexity correlated to higher clearances of preference and interest of certain stimuli. Consistent to the findings of Bailes & Dean 2009), this is unsurprising, though this study was able to uncover that spectral gesture performed stronger than spectral structure. Results of spectral flux and spectral entropy aligned to the predictors and regression models of Gingras et al. (2013), further cementing the impacts of timbral qualities on listener preference. It was found that listeners preferred sounds with higher timbral complexity or texture, though the affect of emotion (see Hailstone 2009) was not tested. Regardless, composers should be mindful of these studies in amalgamation when composing electroacoustic music, to understand that higher complexities of timbre improve listener preference. Similarly, listeners chose sounds with a larger spectral gesture and structure as being more interesting than their less complex pairs. Additionally, Means of Association testing against all 3036 profiles indicated that listeners have a high aptitude for correctly identifying sounds which are more complex in spectral categorisations (H03). In support of hypothesis three, the structural composition of a sound influenced a listener's assumptions of complexity and completeness relating to that sound. Eighty-six percent of listeners Listeners were significantly more likely to find sounds with a larger spectral gesture (83%) and spectral structure (79%) as being more complex (83%). Similarly, listeners were significantly more likely to choose sounds with larger spectral gesture and structure as seeming more complete. These results align to the results of neurological studies in which sounds with higher rates of harmonic information stimulate enhanced responses in listeners when compared to duller counterparts (Kuriki et al., 2007; Tremblay 2007). Though this current study is limited to perceptual experience, future work will aim to identify the links between perceptual and neurological experience of spectromorphological matter.

Overall, spectral gesture held the highest Impact Ranking, with an average Means of Association across preference, complexity, interest and completeness (Table 3). Across all categories, Means of Association were consistently high for both spectral and gestural properties and thus should be treated as valid in impacting a listener's preference, complexity, interest and completeness of auditory stimuli. These findings demonstrate the power of intentional computer processing on electroacoustic sounds to increase preference. In confirming that listeners prefer more complex sounds, composers and audiophiles alike can use this knowledge to shape the way they compose for their listeners.

The results of this study are beneficial not only in terms of their psychological consequences but also their implications for electroacoustic music composition. The non-arbitrary nature of these findings indicate that composers should be mindful of the spectromorphological and acoustic complexity of their compositions, to potentially increase the satisfaction of their listeners. In the same way that Gingras et al. (2014) were able to effectively predict a variance in emotional response to various spectral paradigms, the results of this study can inform the practice of electroacoustic preference. For example, understanding that listeners prefer more complex time series frequencies might inform composers to utilise more experimental techniques in their practice.

Conclusion

This study reveals that listener's perception, preference and understanding of electroacoustic cues are highly interrelated with the true spectral complexity of the stimuli themselves. These findings are consistent with research in neurological fields (see Kuriki et al., 2007; Tremblay 2007), suggesting that listener's perceptual experiences are heavily impacted by spectromorphological complexity. As a result, there is a need for composers to consider how the deliberate use of spectral complexity can inform future methods of compositional practice for the purpose of enhancing listener enjoyment and interest. While this study focused on spectromorphological properties, the next step is to investigate their correlation to any impacts of spatial, temporal and amplitudinal complexity on listener perception. Electroacoustic music can be digitally manipulated or treated in a way that is not always afforded to other presentations of analog playback or physical music performance. This control allows composers to have a significantly high degree of control over the inner-acoustic properties of the sounds they emit. By understanding and orchestrating the manipulation of these properties, modern computer-music composers can create higher degrees of spectral complexity to increase listener satisfaction.

	Preference (*r*)	**Complexity** (*r*)	**Interest** (*r*)	**Completeness** (*r*)	**Averages** (*r*)	**Effect Size**
Spectral Gesture	.54**	.54**	.54**	.53**	.54**	High
Spectral Structure	.47**	.49**	.46**	.46**	.47**	Medium

**. Correlation is significant at the 0.01 level (1-tailed).

Table 3. Pearson Correlation Coefficient of Totals

References

Anikin, A. (2019). Soundgen: An open-source tool for synthesizing nonverbal vocalizations. Behavior Research Methods, 51(2), 778-792. https://doi.org/10.3758/s13428-018-1095-7

Araya-Salas, M., & Smith-Vidaurre, G. (2017). warbleR: an r package to streamline analysis of animal acoustic signals. Methods in Ecology and Evolution, 8(2), 184-191. https://doi.org/https://doi.org/10.1111/2041-210X.12624

Bailes, F., & Dean, R. T. (2012). Comparative Time Series Analysis of Perceptual Responses to Electroacoustic Music. Music perception, 29(4), 359-375. https://doi.org/10.1525/ mp.2012.29.4.359

Bardy, F., Van Dun, B., & Dillon, H. (2015). Bigger Is Better: Increasing Cortical Auditory Response Amplitude Via Stimulus Spectral Complexity. Ear and Hearing, 36(6), 677-687. https://doi.org/10.1097/AUD.0000000000000183

Boersma, P. W., David. (2022). Praat: doing phonetics by computer [Computer program] (Version Version 6.2.19). http://www.praat.org/

Burns, T., & Rajan, R. (2019). A Mathematical Approach to Correlating Objective Spectro-Temporal Features of Non-linguistic Sounds With Their Subjective Perceptions in Humans. Frontiers in neuroscience, 13, 794-794. https://doi.org/10.3389/fnins.2019.00794

Cross, T. (2018). Reflective Practice in Hybrid Sound Fields: Reconceptualising Sound-Based Composition for the Mixed Reality Continuum, The University of Sydney].

Cross, T. (in press). Reframing sound-shapes in spectromorphological composition: Notating Space through Spherical, Euclidean and Cartesian-Coordinate Systems, Organised Sound: An International Journal of Music Technology, [In Review].

Cruces-Solís, H., Jing, Z., Babaev, O., Rubin, J., Gür, B., Krueger-Burg, D., Strenzke, N., & Hoz, L. d. (2018). Auditory midbrain coding of statistical learning that results from discontinuous sensory stimulation. PLoS Biology, 16(7), e2005114. https://doi.org/10.1371/ journal.pbio.2005114

Dobrowohl, F. A., Milne, A. J., & Dean, R. T. (2019). Timbre Preferences in the Context of Mixing Music. Applied sciences, 9(8), 1695. https://doi.org/10.3390/ app9081695

Donderi, D. C. (2006). Visual Complexity: A Review. Psychological bulletin, 132(1), 73-97. https://doi.org/10.1037/0033-2909.132.1.73

Durmus, D. (2020). Spatial Frequency and the Performance of Image-Based Visual Complexity Metrics. IEEE access, 8, 100111-100119. https://doi.org/10.1109/ ACCESS.2020.2998292

Fleiss, J. L. (1971). Measuring nominal scale agreement among many raters. Psychological bulletin, 76(5), 378-382. https://doi.org/10.1037/h0031619

Geake, J. (1997). Individual Differences in the Perception of Musical Coherence. Journal of New Music Research, 26(3), 201-226. https://doi.org/10.1080/09298219708570727

Gomez-Marin, A., Paton, J. J., Kampff, A. R., Costa, R. M., & Mainen, Z. F. (2014). Big behavioral data: psychology, ethology and the foundations of neuroscience. Nature Neuroscience, 17(11), 1455-1462. https://doi.org/10.1038/nn.3812

Gomez-Marin, A., Paton, J. J., Kampff, A. R., Costa, R. M., & Mainen, Z. F. (2014). Big behavioral data: psychology, ethology and the foundations of neuroscience. Nature Neuroscience, 17(11), 1455-1462. https://doi.org/10.1038/nn.3812

Honingh, A., Panteli, M., Brockmeier, T., López Mejía, D. I., & Sadakata, M. (2015). Perception of timbre and rhythm similarity in Electronic Dance Music. Journal of New Music Research, 44(4), 373-390.

Juslin, P. N., & Laukka, P. (2004). Expression, Perception, and Induction of Musical Emotions: A Review and a Questionnaire Study of Everyday Listening. Journal of New Music Research, 33(3), 217-238. https://doi.org/10.1080/0929821042000317813 Kamalzadeh, M., Baur, D., & Möller, T. (2016). Listen or interact? A Large- scale survey on music listening and management behaviours. Journal of New Music Research, 45(1), 42-67. https://doi.org/10.1080/09298215.2015.1133655

Kraus, N., Skoe, E., Parbery-Clark, A., & Ashley, R. (2009). Experience-induced Malleability in Neural Encoding of Pitch, Timbre, and Timing: Implications for Language and Music. Annals of the New York Academy of Sciences, 1169(1), 543-557. https://doi.org/10.1111/ j.1749-6632.2009.04549.x

Kuriki, S., Ohta, K., & Koyama, S. (2007). Persistent Responsiveness of Long-Latency Auditory Cortical Activities in Response to Repeated Stimuli of Musical Timbre and Vowel Sounds. Cerebral Cortex, 17(11), 2725-2732. https://doi.org/10.1093/cercor/bhl182

Levine, T. R., & Hullett, C. R. (2002). Eta Squared, Partial Eta Squared, and Misreporting of Effect Size in Communication Research. Human communication research, 28(4), 612-625. https://doi.org/10.1111/ j.1468-2958.2002.tb00828.x

Lloyd, T., Gaydecki, P., Johannsson, H., Ginsborg, J., & Yates, C. (2018). Listener preference towards a real and emulated violin. Journal of New Music Research, 47(3), 270-274. https://doi.org/10.1080/09298215.2018.1459732

MacKay, J. (1984). On the perception of density and stratification in granular sonic textures: An exploratory study. Interface, 13(4), 171-186. https://doi.org/10.1080/09298218408570451

MATLAB. (2022). (Version R2022a). The MathWorks Inc.

Norman-Haignere, S., Kanwisher, Nancy G., & McDermott, Josh H. (2015). Distinct Cortical Pathways for Music and Speech Revealed by Hypothesis-Free Voxel Decomposition. Neuron (Cambridge, Mass.), 88(6), 1281-1296. https://doi.org/10.1016/j.neuron.2015.11.035

Nyström, E. (2011). Textons and the Propagation of Space in Acousmatic Music. Organised sound : an international journal of music technology, 16(1), 14-26. https://doi.org/10.1017/S1355771810000397

Pearce, M., & Müllensiefen, D. (2017). Compression-based Modelling of Musical Similarity Perception. Journal of New Music Research, 46(2), 135-155. https://doi.org/10.1080/09298215.2017.1305419

Schaeffer, P., North, C., & Dack, J. (2017). Treatise on musical objects: essays across disciplines (Vol. 20). University of California Press.

Shahin, A., Roberts, L., Miller, L., McDonald, K., & Alain, C. (2007). Sensitivity of EEG and MEG to the N1 and P2 Auditory Evoked Responses Modulated by Spectral Complexity of Sounds. Brain Topography, 20(2), 55-61. https://doi.org/10.1007/s10548-007-0031-4 Shahin, E. A., Roberts, J. L., Pantev, J. C., Trainor, J. L., & Ross, J. B. (2005). Modulation of P2 auditory-evoked responses by the spectral complexity of musical sounds. NeuroReport, 16(16), 1781-1785. https://doi.org/10.1097/01.wnr.0000185017.29316.63

Shetake, J. A., Engineer, N. D., Vrana, W. A., Wolf, J. T., & Kilgard, M. P. (2012). Pairing tone trains with vagus nerve stimulation induces temporal plasticity in auditory cortex. Experimental Neurology, 233(1), 342-349. https://doi.org/10.1016/j.expneurol.2011.10.026

Singh, N. C. (2011). Measuring the 'complexity' of sound. Pramāṇa, 77(5), 811-816. https://doi.org/10.1007/ s12043-011-0188-y

Smalley, D. (1986). Spectro-morphology and Structuring Processes. In S. Emmerson (Ed.), The Language Electroacoustic Music (1st 1986. ed., pp. 61 - 93). Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-18492-7

Smalley, D. (1996). The listening imagination: Listening in the electroacoustic era. Contemporary Music Review, 13(2), 77-107. https://doi.org/10.1080/07494469600640071

Smalley, D. (1997). Spectromorphology: Explaining Sound-Shapes. Organised sound : an international journal of music technology, 2(2), 107-126.

Stenslie, S. (2006). Symbiotic Interactivity in Multisensory Environments. In R. Ascott (Ed.), Engineering nature : art & consciousness in the post-biological era. Intellect. Table of contents onlyhttp://www.loc.gov/catdir/toc/ fy0610/2006278784 html

Sueur, J., Aubin, T., & Simonis, C. (2008). Seewave, a Free Modular Tool for Sound Analysis and Synthesis. Bioacoustics, 18(2), 213-226. https://doi.org/10.1080/09524622.2008.9753600

Team, R. C. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/.

Tervaniemi, M., Schröger, E., Saher, M., & Näätänen, R. (2000). Effects of spectral complexity and sound duration on automatic complex-sound pitch processing in humans – a mismatch negativity study. Neuroscience letters, 290(1), 66-70. https://doi.org/10.1016/S0304-3940(00)01290-8

Thoresen, L. (2007). Spectromorphological Analysis of Sound Objects: An Adaptation of Pierre Schaeffer's Typomorphology. Organised Sound, 12(2), 129-141.

Tremblay, K. (2007). Training-Related Changes in the Brain: Evidence from Human Auditory-Evoked Potentials. SEMINARS IN HEARING, 28(2).

Wang, X. (2013). The harmonic organization of auditory cortex. Frontiers in systems neuroscience, 7, 114. https://doi.org/10.3389/fnsys.2013.00114.

CHAPTER FIVE

Notating Morphological Complexity

5.1 Introduction

Having explored the perceptual impact of spectromorphological complexity in electroacoustic music composition in Chapter 3, and further investigated the role of spatiotemporal complexity in Chapter 4, it is now crucial to delve deeper into the challenges and possibilities of notating and manipulating sound in three-dimensional sound environments. This brings us to Paper 3, which focuses on Smalley's preliminary taxonomy of sound-shapes and the development of a method to adapt these shapes for the notation of sound in three-dimensional space.

This chapter addresses the inherent challenge of accurately capturing spatial information in graphical notation, particularly in relation to time, space, and frequency. By introducing the concept of a point of origin (O) within Cartesian environments, the study successfully resolves the issue of spatial accuracy, enabling composers to plot sound shapes representative of morphological space alongside time and frequency. The utilization of coordinate values for space, analogous to the scales of time and frequency, offers a comprehensive approach to notating spectral, spatial and temporal information. Additionally, the study explores the distribution of characteristics between spectral, spatial, and temporal nodes through the use of groupings, presenting a framework for interchangeability within sound-shapes. By incorporating the knowledge gained from Chapters 3 and 4 on the perceptual complexities of electroacoustic cues, this chapter serves as a crucial bridge, taking us from theoretical and analytical frameworks to practical applications in electroacoustic music composition.

The findings of this study served as the practical catalyst for the following Appendices:

APPENDIX D. PAPER 5

Cross, T. (2019). Schema: Looking Toward a Post-Biological Composer. *CTM 2019 Persistence*, 20th Edition: Disk Publishing.

APPENDIX E. COMPOSITION

Cross, T. composer. "Schema". MONOM, Berlin, Germany, 2019.

PAPER 3

Cross, T. (in press). Reframing sound-shapes in spectromorphological composition: notating perspectival space through spherical, Euclidean and cartesian-coordinate systems, *Organised Sound.*

Research Paper

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Analysing the Acoustic, Perceptual and Morphological Correlations of Spatial, Temporal and Amplitude Complexity in Electroacoustic Stimuli *(in review)*

Tiernan Cross

Abstract

Spatiomorphology provides a theoretical framework for composers to create immersive and engaging electroacoustic music. This framework emphasises the relationships between sound, space and structure within electroacoustic settings. With music, acoustics and space becoming increasingly intertwined and malleable in developing technological landscapes, it is crucial to comprehend the correlations between morphological properties and listener experience, perception, preference, and understanding. This study investigates the impact of varying complexities of spatial, temporal and amplitude structures in auditory stimuli on listener experience. In this study the spatial, temporal and amplitude properties of ninety stimuli were measured based upon their complexity, texture, range of motion, roughness and syllabic structure, and linked to relevant morphological groupings. Twenty-three participants then evaluated these stimuli in pairs, providing responses on preference, presumed complexity, presumed completeness, and level of interest. This study tested the hypotheses that higher rates of spatial, temporal and amplitude morphology could positively influence listener preference, interest, and assumptions in electroacoustic settings. Results indicated that spatial structure and modulation strongly affect listener responses, with spatial gestures having an even greater impact than spectral structure. Higher levels of spatial and amplitude complexity correlated with higher rates of preference and interest, with the structural composition of a sound influencing listeners' assumptions of complexity and completeness. The complexity of amplitude and temporal properties also demonstrated positive correlation to listener experience and understanding of sounds. These findings deliver a more complete understanding a listener's perception to common electroacoustic paradigms and should be used to inform future methods of creativity in computer music composition.

Keywords
spatiomorphology, music cognition, electroacoustics, computer music, music composition

Introduction

Electroacoustic music offers a unique opportunity to explore the relationship between sound and listener perception. Effective composition in this medium requires a comprehensive understanding of both the acoustic properties of sound, their morphologies and the perceptual mechanisms that shape our experience of stimuli. Increased rates of spectromorphological change in auditory stimuli has been found to positively impact listener perception, preference, and understanding (Cross, in review a), though the effects of spatiotemporal morphologies on perceptual experience remain unknown. The next challenge is to understand the perceptual impacts of non-spectromorphological properties such space, time and amplitude. This study investigates the influence of spatial, amplitude, and temporal complexities on listener preference, experience and understanding. This study draws upon the theoretical framework of Denis Smalley's morphologies (1986; 1996; 1997), which emphasise the relationship between sound, spectra and space in electroacoustic music. Smalley's framework provides a means of categorising spatiomorphological properties of sound by their attributes of spatial texture, gesture, amplitudinal and temporal structures, which can in turn be linked to paradigms of modern acoustic and time series analyses (see Figure 1). By investigating the correlations between spatiotemporal complexity and listener preference, this research will draw previously unknown conclusions on the effects of morphological complexity on listener perception.

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Literature

Several characteristics of electroacoustic music have been found to correspond with measures of affect. Isolated perceptual preference and contrast effect tests have demonstrated that acoustic complexity can significantly impact listener arousal, preference, and emotional response to musical stimuli (Bailes & Dean, 2012; Lloyd et al., 2018; Smit et al., 2022; Juslin & Vastfjall, 2008). Cross, (in review b] employed Smalley's morphological model to determine that higher levels of spectral gesture and structure resulted in both increased morphological complexity and increased preference, understanding, and satisfaction among listeners. Extending Cross' methods of standard signal processing measures, this research investigates whether the complexity of non-spectral (spatial, amplitude and temporal) morphologies generate similar correlations of positive listener experience, understanding and understanding.

This study proposes three hypotheses relating to the complexity of spatial (H1), temporal (H2) and amplitude (H3) morphology. The first hypothesis is that listener preference and interest are influenced by the spatial complexity of electroacoustic stimuli, in terms of gesture, motion, structure, texture and density. A second hypothesis suggests that higher levels of amplitude complexity result in greater preference, interest and presumed completeness of stimuli. The third hypothesis suggests that higher levels of temporal morphology will positively correlate to listeners' perceptual preference, interest and assumed completeness of auditory stimuli.

Spatial Complexity

Sounds with higher rates of sonic information have been found to enhance cognitive and emotionalresponses in listeners (Huron 2019, Grewe et al. 2007; Juslin et al., 2008). Similarly, localisation tests have indicated that sounds with greater spatial complexity led to higher rates of auditory attention and memory performance (Ismail 2017; Lloyd et al., 2018). In fields of acoustics, spectral, structural, timbral, and spatial structures have been determined to influence listener experience (Choisel & Wickelmaier 2006; McAdams, Douglas, & Vempala, 2017; Caclin et al., 2005; Juslin & Laukka, 2004). Similarly, the inclusion of intricate patterns and fluctuations within brief cues has been found to significantly enhance the aesthetic appeal and emotional impact on listeners (Schubert, 2013; Barthet et al., 2010). Together these findings suggest that the spatial complexity of sounds can play a crucial role in shaping neural responses and ultimately influence the subjective experience of listening. Though Cross (in review a) illustrated that auditory stimuli with complex spectral morphologies generate similar trends of positive listener experience to neural counterparts, little is known regarding the effects of spatial, temporal and amplitude- based morphologies on perception. In the same way that perceptual responses to spectral morphologies have mimicked neural responses, the author anticipates that spatiomorphological complexity would also demonstrate positive correlations. As such, this study will examine whether the complexity of spatial gesture and spatial motion morphologies generate similar trends of positive listener experience (H1).

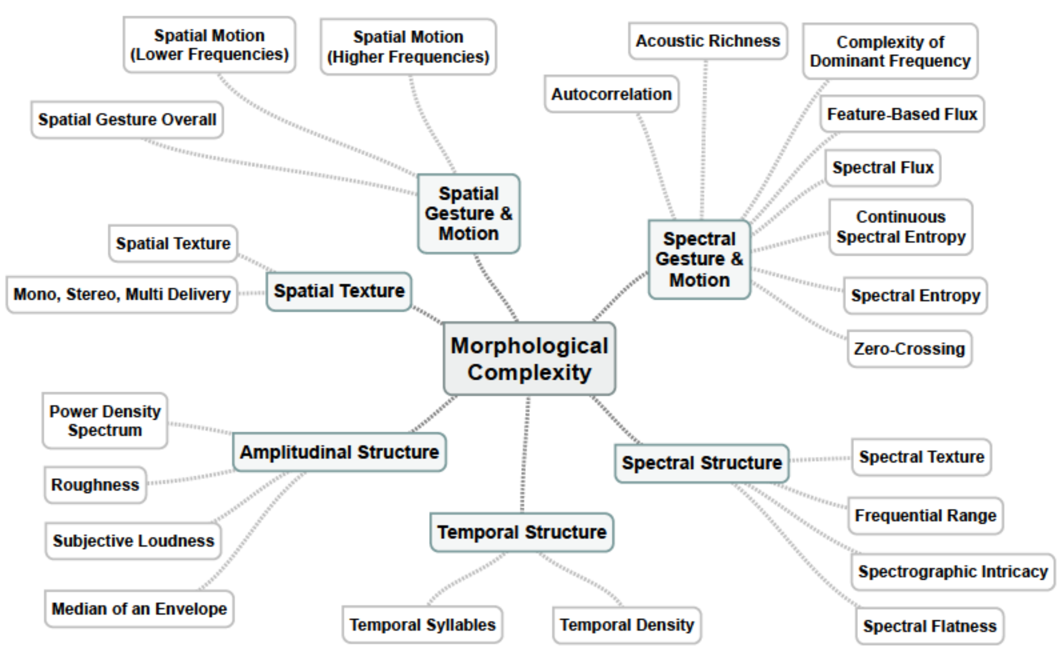

Figure 1: Bridging morphology with corresponding acoustic and signal processing measures (Cross, in review a)

Amplitude Complexity

The second hypothesis suggests of this study anticipates that higher levels of amplitude complexity will result in greater preference, interest and presumed completeness of stimuli. The ability to manipulate and control amplitude complexity through digital signal processing also allows for the creation of more intricate and engaging auditory experiences. Roughness or amplitude complexity impacts listener preference and perception of sound quality, particularly in the context of musical timbres (Barthet et al., 2011; Eerola, Ferrer & Alluri 2012). The degree of these impacts may depend on other factors, such as modulation depth and frequency, carrier frequency, and individual listener characteristics. As such, this research will examine whether the overarching umbrella of amplitude morphology by a combination of power density spectrum (pwelch), roughness (acousticRoughness), subjective loudness (acousticLoudness) and the median amplitude of an envelope (M) generate similar trends of positive listener experience (H2).

Temporal Complexity

Stimuli with higher temporal information, such as those with rapid changes in pitch or timing, have been found to elicit stronger neural responses in areas associated with auditory processing and perception (Kraus et al., 2009), though to mixed results with Huron (2006) finding weak correlations. One potential reason for the mixed results is that the effects of temporal complexity may be dependent on other factors, such as the specific musical genre or the individual listener's musical experience (Huron, 2006). Further research is needed to better understand the complex relationship between temporal complexity and listener experience in musical and acoustic settings. Therefore, hypothesis three is that the morphological characteristics linked to temporal acoustic parameters will positively impact listener experience in certain settings. From here, it is predicted that the median envelope of a sound (temporal density) over time will hold higher impact than other areas. The author hypothesises that the number of temporal syllables of a sound will increase the complexity and temporal structure and therefore increase listener preference.

Method

Participants

In this study, 23 participants were recruited, ranging in age from 22 to 49, with a median age of 34. The participants had varying levels of computer music proficiency, with 12 (52%) reporting proficiency in computer music theory and/or composition, and 11 (48%) reporting no proficiency in this area. All participants confirmed that they did not have any known hearing impairments. Each participant self-reported their level of musical ability in theory, composition, and performance, which ranged from high (26%), above average (18%), average (35%), to very little musical ability (21%). Sex and/or gender were not considered as demographic variables during analysis, as previous research has suggested that they do not have a significant impact on perceptual studies (Durmus, 2020).

Stimuli

Ninety electroacoustic stimuli were created and categorised based upon common components of morphological complexity. The duration of sounds ranged from 0.51 seconds to 5.98 seconds in duration. The average duration of all sounds was 3.24 seconds. Each sounds' structure was informed by Smalley's categorisations of spatiomorphology (Smalley, 1986, 1996, 1997), with each stimuli incorporating measurable components that could be linked to Smalley's morphological classifications of gesture, motion, texture, modulation and structure.

Acoustic Analyses

MATLAB (MATLAB, 2022), R (Team, 2022) and PRAAT (Boersma, 2022) were utilised to analyse the structure and complexity of each sound's spatial, temporal and amplitude complexity, based upon the acoustic properties and morphological by-products outlined in Figure 1. The complexity of the sounds was assessed by measuring the amount of information each query returned. The stimuli with higher rates of information were considered more complex in their respective categories for this study, which is consistent with previus theoretical and perceptual studies (Donderi, 2006; Durmus, 2020; Nyström, 2011).

Spatial Gesture was measured through the processing of spatial motion in various frequential bandings, while spatial structure was measured through calculating the rates and locations of textons within space (spatial texture) (Donderi, 2006; Durmus, 2020; Nyström, 2011)), in conjunction with polar coordinate values of stimuli. Amplitude structure was analysed through the processing of the power density spectrum (pwelch), roughness (acousticRoughness), subjective loudness (acousticLoudness) and the median amplitude of an envelope (M). Temporal structure and "temporal density" (MacKay, 1984) p. 178) was measured through the analysis of continuous acoustic segments, known as temporal syllables.

Data Analyses

Spatial Complexity

To investigate the spatial structure of electroacoustic music, spatial gesture, motion, and texture were analysed. To measure spatial gesture, real-time computation of stereophonic frequency positioning was performed using FLUXAnalyser and Izotope Ozone Imager. FLUXAnalyser's Nebula Spatial Spectrogram provided precise results by constraining a spectrum-space frame to the stereo field and controlling short-term blur and dimming values. The calculation of spatial gesture was based on the non-static movements of spectra, catalogued by the spatial motion of frequencies within three ranges: 0-200 Hz, 201 Hz - 20 kHz, and the total frequential field. Similarly, spatial texture was evaluated by employing polar coordinate plots per sample to determine the spatial placement of incoming spectra across the stereo field, as detailed by Cross (2018, p. 52). The stereophonic value of each object was averaged to obtain an overall reading for each stimuli. Each sound in the study was subjected to paired comparison, with its original recording serving as the reference against its augmented variant. To evaluate the complexity of each stimulus, spatial features were measured using FLUXAnalyser, amplitude features were assessed using MATLAB, and temporal features were analysed using RStudio.

Ampiltude and Temporal Complexity

The perceived loudness of each acoustic signal was evaluated using subjective loudness estimations in MATLAB (acousticLoudness) and verified through soundgen getLoudness queries (see Figure 2), with no data being excluded from the analysis. The roughness, or amplitude modulation, was measured using MATLAB's acousticRoughness queries (see Figure 3), and again all 90 sounds were evaluated. The acoustic index, which was based on the median of the amplitude envelope (M), was compared to pairings with different spectral frequencies. The analysis of M was performed using a one-way ANOVA to investigate the variance between the median and presumed complexity. Additionally, the overall power density spectrum (pwelch) of each stimulus was calculated by measuring the power distribution (in dB) against the normalised frequency (2 π 1000 / 44100) over time. MATLAB's pwelch was used to obtain the power spectral density estimate for all 90 stimuli in the study (see Figure 4). The study employed audio segmentation to capture continuous syllables and acoustic bursts to measure the temporal structure of each stimulus. The soundgen package's segment function was used to detect audio bursts based on both amplitude envelopes and frequency spectrograms. The syllabic structure of each sound was determined through this process.

Perceptual Analysis

A/B preference tests were conducted in which listeners provided subjective responses to each stimulus in terms of preference, presumed complexity, presumed completeness, and their level of interest. The test was conducted using headphones, with 9 (39%) participants using high-quality/ professional headphones and 14 (61%) using low-quality/ everyday headphones. A total of 3036 responses were collected and combined into a robust dataset, which was then analysed using common statistical methods to identify key trends in the listeners' preferences for electroacoustic structure and sound cues. The results of

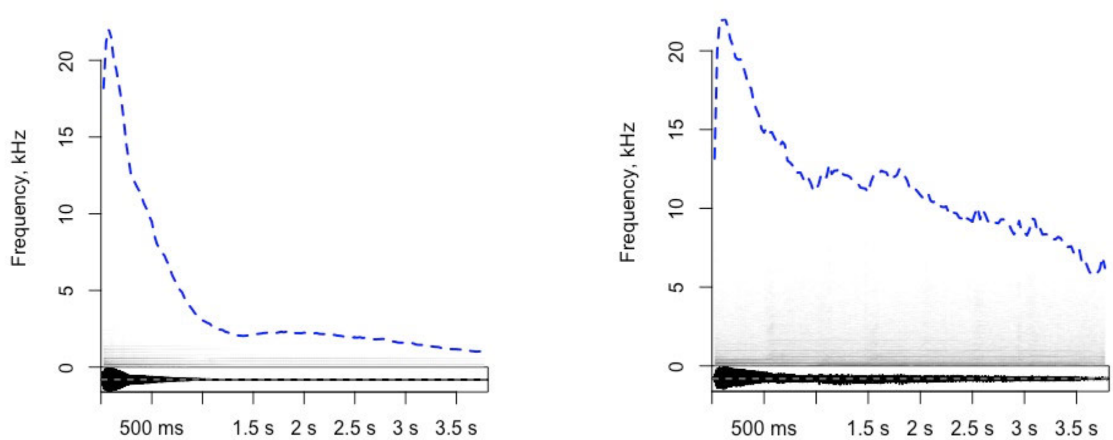

Figure 2: The visual representation of *subjective loudness* of two stimuli over the same time-series. Lower values indicate lower levels of *subjective loudness* (left), while constantly higher values indicate higher levels of overall *subjective loudness* (right). Sounds with higher values of subjective loudness performed approximately 85% better than softer sounds in subjectivity tests on *preference, complexity, interest* and *completeness*.

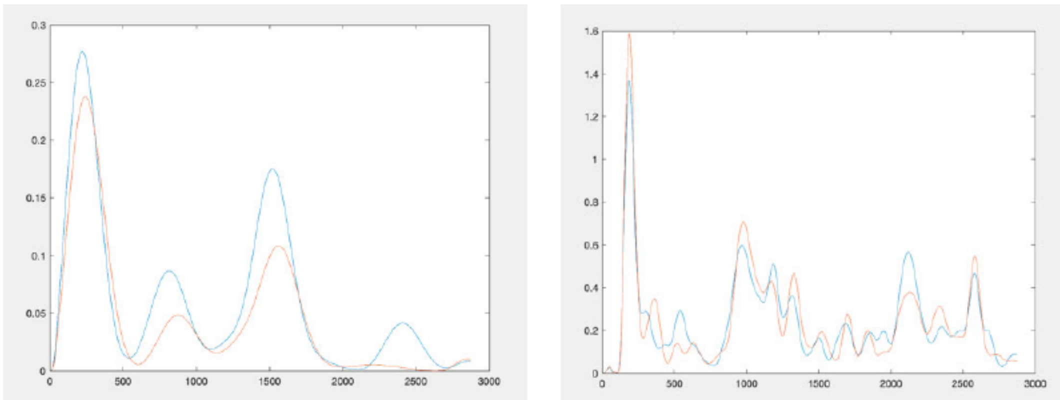

Figure 3: The visual representation of *acoustic roughness* of two stimuli over the same time-series. Lower visual intricacy indicates lower levels of *roughness* (left), while higher values indicate higher levels of overall *roughness* (right).

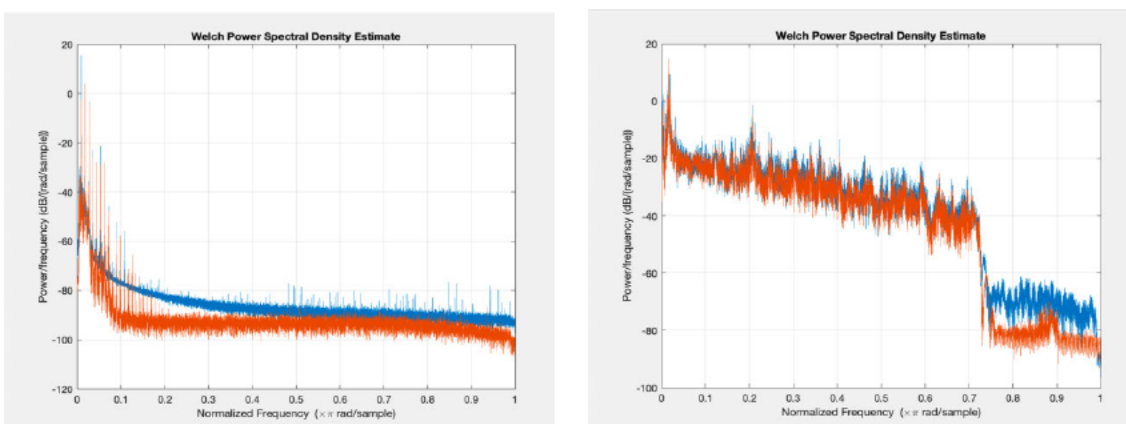

Figure 4: The visual representation of *Power Spectral Density Estimates* of two stimuli over the same time-series.

these subjective perceptual assessments are presented in this study and mapped to overarching morphological categories (see Figure 1), to provide empirical evidence that certain morphological features of sound are perceived and processed by listeners in a consistent manner.

The relationship between listener response and stimuli structure was assessed using Pearson coefficient correlation models for each acoustic property. The aim was to test hypotheses regarding the influence of certain spectral complexities on listener preference, presumed complexity, presumed completeness, and level of interest. Effect levels were also determined, examining the interactions between fixed and continuous variables of stimuli properties and dependent and discrete variables of listener response. Perceptual tests provided positive (+1) or negative (-1) scores based on the listener's preference, interest, and assumption of each stimulus, which were analysed both individually and as a cohort to identify trends. Supplementary model testing was performed to streamline variance percentages using Eta squared readings (ANOVA model), and statistical significance was assessed across all models using Pearson Chi Squared.

Procedure

The institutional ethics committee approved the project. Participants read an information statement and provided consent individually prior to commencement. Listening sessions lasted for approximately fifteen minutes and were conducted virtually using REDCap, a metadata-driven survey application for managing online surveys, due to COVID-19 restrictions. Participants were instructed to listen to a series of 90 two-second musical cues and complete an accompanying questionnaire describing their preferences, selectivity, and understanding of which of the paired cues sounded more complex, interesting, and complete. The cues were played in a random order to avoid skewing the results. Each of the ninety stimuli was presented to participants in pairs alongside another sound of similar spectral property. Within each pairing, the order of each sound was randomised, and labelled Sound A or Sound B. Listeners were asked to indicate their preference, interest, and comprehension of each sound's complexity. For each pairing, participants were instructed to play and replay both Sound A and Sound B as they answered the following four questions:

(1) Which cue do you prefer?
(2) Which cue do you find to sound more complex?
(3) Which cue do you find more interesting?
(4) Which cue do you find sounds more complete?

Results

Spatial Motion and Texture

Table 1 presents a summary of the Means of Association, as measured by the Pearson Correlation Coefficient, between spatial motion and spatial texture against listener preference, level of interest, assumed complexity, and assumed completeness. The summary is based on the analysis of all 3036 response profiles. Spatial texture had a significant impact on listener experience, with extremely high correlations to preference ($r = .62$), assumed complexity ($r = .62$), level of listener interest ($r = .64$), and assumed completeness ($r = .66$) outperforming all other categories. The Eta squared readings indicated a high level of association between spatial texture and listener perception (ANOVA, χ^2 (25, N = 90) = 7.71, $p < .001$)). These results confirm that spatial texture is a crucial factor in shaping listener experience. Similarly, overall spatial motion was linked to preference ($r = .68$), complexity ($r = .72$), level of interest ($r = .69$) and completeness ($r = .66$) with 87% of listeners preferring sounds with higher rates of spatial motion. Ninety-two percent of listeners correlated higher rates of spatial motion to higher levels of complexity.

The Spatial Motion of higher frequencies (0 – 200 Hz) recorded lower coefficients than overall spatial motion in all four categories, with preference ($r = .68$), complexity ($r = .83$), level of interest ($r = .70$) and completeness ($r = .66$). Despite these lower coefficients, 83% of stimuli with the more spatial motion in higher ranges were considered by listeners to be more preferred and more complex. These returns indicate a high level of attribution between spatial textons and listener experience, with the stronger correlations of global spatial motion indicating that the more movement overall, the better the listener experience, interest and presumed complexity. Stimuli with Spatial Motion of lower frequencies (2 – 20 kHz) held the lowest coefficient associations in the category of spatial motion, with preference ($r = .14$), complexity ($r = .11$), level of interest ($r = .15$) and completeness ($r = .13$).

Eighty-four percent of sounds with a higher spatial motion within the ranges of 0-200Hz were deemed more preferred, interesting, complete and/or complex then their less-complex counterparts. Higher frequencies with wider, less static topographies were more preferable, with a statistically significant relationship between preference and spatial motion (F (2,87) = 65.45, $p < .001$, $\eta^2 = <0.60$). This aligns with norms in which bass notes or frequencies are centred in the LR spectrum of modern mixing techniques. Whilst still comparatively high, compared to spectral properties, spatial motion in the upper harmonic ranges of sounds held the lowest performance rate average of 83%. Comparisons were made between stereophonic and monophonic stimuli, with a focus on the preferences of listeners. Stereophonic sounds were preferred by listeners 92% of the time. Moreover, 98% of occasions yielded higher ratings for the complexity of stereophonic sounds, and 95% of the data revealed greater interest in stereophonic sounds compared to monophonic sounds. Additionally, 92% of the data indicated that stereophonic stimuli were perceived as more complex. Across the 3036 data set, 94% of readings favoured or deemed stereophonic sounds to be more complex than monophonic sounds.

Amplitude and Temporal Structure

The results of the Power Density Spectrum analysis exhibited strong correlations with assumed completeness ($r = .58$) and level of interest ($r = .64$), indicating its impact on all four categories of preference, complexity, interest, and completeness (Table 2). However, its influence was not as strong as that of Spatial Motion ($r = .69$). Most pairings (82%) perceived stimuli with a stronger (or equal power spectrum) to belong to the sound that was considered by listeners to be more preferred, with a similar proportion (84%) attributing higher complexity to those sounds. The findings for interest and completeness were also high, with approximately 82% of participants indicating the stimuli with stronger power spectra as being more interesting and complete. The pwelch analysis yielded a high correlation ($r = .61$), with listeners preferring sounds with stronger signal power.

	Preference	Complexity	Interest	Completeness	Averages	Effect Size
Spatial Motion - Overall	0.68**	0.72**	0.69**	0.66**	0.69	High
Higher Spatial Motion - 2 - 20 kHz	0.68**	0.73**	0.70**	0.66**	0.69	High
Lower Spatial Motion 0 – 200 Hz	0.14**	0.11**	0.15**	0.13**	0.16	Low
Spatial Texture	0.62**	0.62**	0.64**	0.69**	0.64	High

**. Correlation is significant at the 0.01 level (1-tailed).

Table 1. Pearson Correlation Coefficient of Spatial Structure, Motion & Texture.

	Preference (*r*)	Complexity (*r*)	Interest (*r*)	Completeness (*r*)	Averages (*r*)	Effect Size
Power Density Spectrum	.61**	.62**	.64**	.58**	.61	Large
Roughness	-.01 (p = .454)	.00 (p = .499)	-.01 (p = .473)	-.05 (p = .301)	-	Not Significant
Subjective Loudness	.26 (p = .006)	.26 (p = .007)	.27 (p = .006)	.24 (p = .011)	-	Not Significant
Median Amplitude of Envelope	.58**	.58**	.60**	.59**	.59	Large
Temporal Syllables	.30**	.27**	.29**	.31**	.29	Small

**. Correlation is significant at the 0.01 level (1-tailed).

Table 2. Pearson Correlation Coefficient of Temporal and Amplitude Structures

AcousticRoughness values of each stimuli were measured in aspers, and despite measuring insignificant correlations, majority listeners (74%) indicated a preference for stimuli with higher roughness. Additionally, 78% of listeners still perceived the stimuli with higher roughness to be more complex, and 77% perceived them to be more interesting.

Subjective loudness held statistically insignificant relationships with preference (η2 = .26), complexity (η2 = .26), interest (η2 = .27), and completeness (η2 = .24) of auditory stimuli, suggesting that it plays a minor role in shaping listener preferences. These results tell us that a more thorough investigation needs to take place, of either more stimuli or more responses. Of the four areas examined, interest had the strongest correlation with subjective loudness, with 67% of listeners finding the stimuli with a higher mean subjective loudness more interesting. Furthermore, 65% of participants indicated that the stimuli with a higher mean subjective loudness belonged to sounds they perceived as more complete. However, consensus on the relationship between subjective loudness and auditory properties was relatively low, with a majority consensus ratio of 66%. This indicates that subjective loudness may not contribute significantly to the preferability or complexity of auditory stimuli, in comparison to the impact of spatial texture (98%) and spectral gesture (84%). While not statistically significant, the rate of consensus suggests that spectral and spatial properties have a greater impact on subjective preference than amplitude structure.

The analysis of the overall dataset revealed that the median of the amplitude envelope (M) had a significant association with preference (η2 = .58), complexity (η2 = .58), interest (η2 = .60), and completeness (η2 = .59), with an average effect size of η2 = .59. Specifically, 79% of sound pairings showed a preference for the stimulus with the stronger median amplitude, which was also considered more preferred by listeners. Likewise, 82% of sound pairings were associated with sounds deemed more complex. Similarly high percentages were observed for interest (82%) and completeness (80%). Although the median amplitude of the envelope had a noticeable influence on preference, it did not exhibit the same level of impact as spectral and spatial properties.

The measure of attributable association for temporal syllables drew weak correlations in all four areas of preference (η2 = .30), complexity (η2 = .27), interest (η2 = .29), and completeness (η2 = .31). Nonetheless, a clear preference for stimuli with more temporal syllables was observed in 97% of responses for sounds considered more complex and more preferred by listeners. It was also found that preferred sounds contained an average of 9.2 syllables, while unpreferred sounds contained 5.2 syllables. Moreover, sounds deemed more complex by listeners had an average of 9.5 syllables compared to those deemed less complex with an average of 5.5 syllables. Similarly, 97% of pairings preferred stimuli with more temporal syllables for sounds considered more preferred by listeners. Additionally, 94% of participants indicated that sounds with more syllables were more interesting. Sounds deemed more interesting had an average of 150% more syllabic value than those deemed less interesting. Lastly, sounds deemed more complete held an average of 10 syllables, while those deemed less complete held an average of 5 syllables. Results showed that stimuli with more temporal syllables over the same temporal period were generally perceived as more complete and preferred by listeners. This trend was observed in the majority of the 45 stimulus pairings examined in the study.

Summary of Results

Ninety-eight percent of participants agreed that sounds with higher rates of spatial texture were more complex than their acoustically simpler counterpart. Similarly, 96% chose acoustically complex sounds as more interesting, with 93% deeming these both their preferred choice aesthetically, and as sounding more complete. Comparatively, spatial gesture scored slightly weaker in categories of preference (83%), complexity (89%), interest (86%) and completeness (83%). This aligns with results of correlation, in which temporal morphology performed stronger on average (η2 = .68) than spatial gesture (η2 = .64). Amplitude morphology drew the weakest consensus on preference (75%), complexity (78%), interest (77%) and completeness (74%), with a similarly weaker correlation overall (η2 = .48). Despite its weaker performance to spatial and amplitude counterparts, all categories of morphology gained 'high' effect sizes (>0.5) (see Table 3).

Although some stimuli pairings had only minor nuances between them, a clear preference for one sound was evident among the majority of listeners (93%), regardless of age or musical talent. The variance inflation factor (VIF) ranged from 1.135 (for spatial gesture) to 1.391 (for spectral structure), indicating that multiple linear regression outputs would likely be reliable. The measure of association tests was only valid when comparing all 90 sounds and their preferences, rather than just measuring preferred sounds. An overall Pearson Chi-Square test showed that the differences among the categories of more preferred, more complex, more interesting, and more complete were significant ($p < .001$). The overall variance in assumed complexity was highly attributed to higher levels of spatial ($\eta 2 = .67$), amplitude ($\eta 2 = .52$) and temporal complexities ($\eta 2 = .68$). Fleiss kappa measurements (Fleiss, 1971) showed that the degree of actual agreement between complexity and level of interest was $\kappa = .553$ ($p < 0.01$). There was little differentiation between musically inclined ($p = .0003$, $F = 3.12$) and non-musically inclined participants ($p = .001$, $F = 1.94$) who answered all 180 questions. Multicollinearity occurred between the independent variables of spectral gesture and complexity in this pool.

Discussion

This study investigated the influence of spatial, amplitude, and temporal complexities on listener preference, experience and understanding. All four hypotheses were supported by the findings to varying degrees, with results indicating that spatial and amplitude complexities impacted listener preference, interest and understanding of auditory stimuli, whilst temporal complexities bear less, but existent, effect sizes. In support of hypothesis one, results indicated that listener preference was heavily impacted by the level of a sound's spatial complexity in stereophonic environments. Sounds with a higher spatial motion across all harmonic frequencies were considered more complex, while acoustic properties relating to morphological texture returned the highest overall effect sizes. Findings were similarly strong for both spatial gesture and texture. Results showed that spatial complexity significantly affected a listener's perceived sound completeness or complexity, with sounds having higher spatial complexity being perceived as more interesting, complete and complex. Overall, these findings suggest that the spatial structure of acoustic stimuli is a crucial factor that significantly impacts the listeners' experience.

In support of hypothesis two, all four categories of listener preference, interest, complexity and completeness were heavily impacted by the level of a sound's amplitude complexity. Though not entirely morphological, the low returns of subjective loudness were also anticipated. Preference on sounds with higher rates of fluctuation in amplitude were 76%. While still a determining factor, these figures indicate that the amplitude properties of a sound may be less defining in the complexity of a sound than spectral and/or spatial properties (98%). Power Density Spectrum, Roughness and the Median Amplitude of an Envelope all returned high effect sizes. In contrast, Subjective Loudness returned low, but existent, correlation. The results of this study are vital as they offer a spatiotemporal context to previous spectral findings Cross (in review a). Regardless, amplitude structures, particularly that of roughness, can be attributed as a main acoustic dimension that contributes to the perceived timbre of complex sounds. Another dimension of timbre is brought

Morphology	Preference	Complexity	Interest	Completeness	Averages	Effect Size
Spectral	0`.50**	0.52**	0.50**	0.50**	0.50	Large
Spatial	0.62**	0.67**	0.63**	0.64**	0.64	Large
Amplitude	0.51**	0.52**	0.54**	0.48**	0.51	Large
Temporal	0.69**	0.68**	0.69**	0.68**	0.69	Large

**. Correlation is significant at the 0.01 level (1-tailed).

Table 3. Pearson Correlation Coefficients of Differing Morphological Categories.

about by the acoustic properties of spectromorphology, highlighting how the parameters of morphology should be viewed as collaborative parts of a whole. Amplitude morphology holds a relationship to other musical parameters, such as pitch and timbre (Vassilakis & Kendall 2010) that is not necessarily front of mind. In contrast, the impact of temporal factors on the listeners' experience (H3) were relatively mixed. The temporal measure of the median amplitude of an envelope returned high effect sizes, while the density of temporal syllables returned very weak correlation. Together, both categories returned a high, accumulated correlation across all four categories, indicating that the temporal amplitude of a sound plays a significant part in a listener's perceptual experience.

Overall, spatial morphologies drew significantly high correlations across all categories, with spatial texture playing the largest role in shaping perceptual experience, interest and enjoyment. In comparison to the findings of Cross (in review a), the accumulated correlations of spatial morphology outscored the performance of spectral morphology, indicating that the spatial properties of electroacoustic stimuli may play the largest part in affecting a listener's perceptual experience. Similarly, amplitude and temporal morphologies performed significantly well, articulating that the increased complexity of spectral, spatial, amplitude and temporal structures draw strong correlation to the preference, interest, assumed complexity and assumed completeness of electroacoustic phrases.

Conclusion

This study highlights the importance of considering the role of spatiotemporal complexity in the perception and preference of electroacoustic music. The cross-analysis of acoustic properties, morphological trends and perceptual experience allowed us to bridge the gap between theoretical models of sound perception and the subjective experiences of listeners, to contribute to the development of more effective methods for sound design and composition. Spatial complexity, particularly in stereophonic environments, was found to be the most important factor in shaping the listeners' experience, while amplitude and temporal complexities also played substantial roles. These findings align with previous neurological, acoustic and cognitive research (Smit et al. 2019; Burns & Rajan, 2019; Singh, 2011), emphasising the importance of considering morphological complexity in compositional practice to enhance the listener experience. Moreover, this study offers a spatiotemporal extension to previous findings of spectromorphological context. These findings combined are vital for the practice of computer music composition as they enable composers to create more nuanced and expressive music that takes advantage of the full range of sonic possibilities.

As new audio technologies continue to emerge, it necessitates the continual re-evaluation of listener perception. The findings of this paper indicate that longer electroacoustic cues with an emphasis on increased complexities of acoustic properties would also result in more engaging and enjoyable experiences for listeners. Future research will analyse the interplay of spectra, space, amplitude, and spatiotemporal morphological properties in electroacoustic practice to gain a more comprehensive understanding of their combined effects on auditory perception in musical conditions. By experimenting with the complexity of these morphologies in future methods of compositional practice, composers can facilitate the creation of more complex combinations of sound, which proves to be a powerful tool when creating original and engaging electroacoustic music.

References

Barthet, M., Depalle, P., Kronland-Martinet, R., & Ystad, S. (2010). Analysis-by-synthesis of timbre, timing, and dynamics in expressive clarinet performance. Music perception, 28(3), 265-278.

Boersma, P. W., David. (2022). Praat: doing phonetics by computer [Computer program] (Version Version 6.2.19). http://www.praat.org/

Burns, T., & Rajan, R. (2019). A Mathematical Approach to Correlating Objective Spectro-Temporal Features of Non- linguistic Sounds With Their Subjective Perceptions in Humans. Frontiers in neuroscience, 13, 794-794. https:// doi.org/10.3389/fnins.2019.00794

Caclin, A., McAdams, S., Smith, B. K., & Winsberg, S. (2005). Acoustic correlates of timbre space dimensions: A confirmatory study using synthetic tones. The Journal of the Acoustical Society of America, 118(1), 471-482. https:// doi.org/10.1121/1.1929229

Choisel, S., & Wickelmaier, F. (2006). Relating auditory attributes of multichannel sound to preference and to physical parameters (Vol. 3).

Cross, T. (2018). Reflective Practice in Hybrid Sound Fields: Reconceptualising Sound-Based Composition for the Mixed Reality Continuum, The University of Sydney]. Cross, T. (in review b). Analysing the acoustic, perceptual and morphological correlations of spatial, temporal and amplitude complexity in electroacoustic stimuli, Music and Science.

Donderi, D. C. (2006). Visual Complexity: A Review. Psychological bulletin, 132(1), 73-97. https:// doi.org/10.1037/0033-2909.132.1.73

Durmus, D. (2020). Spatial Frequency and the Performance of Image-Based Visual Complexity Metrics. IEEE access, 8, 100111-100119. https://doi.org/10.1109/ ACCESS.2020.2998292

Eerola, T., Ferrer, R., & Alluri, V. (2012). Timbre and Affect Dimensions: Evidence from Affect and Similarity Ratings and Acoustic Correlates of Isolated Instrument Sounds. Music perception, 30(1), 49-70. https:// doi.org/10.1525/mp.2012.30.1.49

Huron, D. (2006). Sweet Anticipation: Music and the Psychology of Expectation. The MIT Press. https:// doi.org/10.7551/mitpress/6575.001.0001

Huron, D. (2019). Musical Aesthetics: Uncertainty and Surprise Enhance Our Enjoyment of Music. Current Biology, 29(23), R1238-R1240. https://doi.org/10.1016/ j.cub.2019.10.021

Ismail, S., Gaydecki, P., Lloyd, T., & Johannsson, H. (2017). Real-Time Emulation of the Acoustic Violin using Convolution and Arbitrary Equalization. Journal of the Audio Engineering Society, 65(5), 367-376. https:// doi.org/10.17743/jaes.2016.0073

Juslin, P. N., & Laukka, P. (2004). Expression, Perception, and Induction of Musical Emotions: A Review and a Questionnaire Study of Everyday Listening. Journal of New Music Research, 33(3), 217-238. https:// doi.org/10.1080/0929821042000317813

Kraus, N., Skoe, E., Parbery-Clark, A., & Ashley, R. (2009). Experience-induced Malleability in Neural Encoding of Pitch, Timbre, and Timing: Implications for Language and Music. Annals of the New York Academy of Sciences, 1169(1), 543-557. https://doi.org/10.1111/ j.1749-6632.2009.04549.x

Lloyd, T., Gaydecki, P., Johannsson, H., Ginsborg, J., & Yates, C. (2018). Listener preference towards a real and emulated violin. Journal of New Music Research, 47(3), 270-274. https://doi.org/10.1080/09298215.2018.1459732

MacKay, J. (1984). On the perception of density and stratification in granular sonic textures: An exploratory study. Interface, 13(4), 171-186. https:// doi.org/10.1080/09298218408570451

MATLAB. (2022). (Version R2022a). The MathWorks Inc.

McAdams, S., Douglas, C., & Vempala, N. N. (2017). Perception and Modeling of Affective Qualities of Musical Instrument Sounds across Pitch Registers. Frontiers in Psychology, 8, 153-153. https://doi.org/10.3389/ fpsyg.2017.00153

Nyström, E. (2011). Textons and the Propagation of Space in Acousmatic Music. Organised sound : an international journal of music technology, 16(1), 14-26.

Schubert, E. (2013). Emotion felt by the listener and expressed by the music: literature review and theoretical perspectives. Frontiers in Psychology, 4, 837-837. https:// doi.org/10.3389/fpsyg.2013.00837

Singh, N. C. (2011). Measuring the ‘complexity’ of sound. Pramāῷa, 77(5), 811-816. https://doi.org/10.1007/ s12043-011-0188-y

Smalley, D. (1986). Spectro-morphology and Structuring Processes. In S. Emmerson (ed.) The Language Electroacoustic Music. London: Palgrave Macmillan UK.

Smalley, D. 1996. The listening imagination: Listening in the electroacoustic era. Contemporary Music Review 13(2): 77-107.

Smalley, D. 1997. Spectromorphology: Explaining Sound- Shapes. Organised Sound : An International Journal of Music Technology 2(2): 107-126.

Smit, E. A., Milne, A. J., Dean, R. T., & Weidemann, G. (2019). Perception of affect in unfamiliar musical chords. PLoS ONE, 14(6), e0218570-e0218570. https:// doi.org/10.1371/journal.pone.0218570

Team, R. C. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/.

CHAPTER SIX

Proof of Concept: Non-Parametric Correlations in Long-Form Composition

5.1 Introduction

Study 3 examined the challenges of notating morphological sound-shapes in electroacoustic environments, considering the relationships between time, space, and frequency. The exploration of Smalley's taxonomy and the adaptation of sound-shapes for Cartesian space provided a starting point for understanding the morphological complexities inherent in electroacoustic music. Study 4 aims to synthesize the cumulative knowledge from the previous studies and incorporate it into a comprehensive framework that embraces the full range of sonic possibilities in longer forms of electroacoustic music composition.

This study will draw upon the findings of Studies 1 and 2, which highlighted the impact of spectromorphological complexity and spatiotemporal factors on listener perception and preference. By integrating these findings with the notational framework developed in Study 3, a refined understanding of compositional practice and the creation of more nuanced and expressive electroacoustic music can be achieved. The stimuli used in Paper 4 can be found in Appendix C.

PAPER 4

Cross, T. (in review c). Morphological fluctuation and listener experience of electroacoustic music: implications for music composition and notation*, Computer Music Journal.*

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Morphological Fluctuation and Listener Experience: Implications for Electroacoustic Composition and Notation (in review)

Abstract: Electroacoustic music has emerged as an innovative area of composition, incorporating a wide range of sonic materials, techniques and technologies. A particular aspect of interest is the role of morphological fluctuation in shaping the listener's experience and understanding of electroacoustic music. Understanding how these fluctuations influence the perception and enjoyment of the music is crucial for composers and researchers in this domain. The aim of this paper is to investigate the role of morphological fluctuation in shaping listener experience and understanding and examines the implications for music composition and notation systems. Ten electroacoustic pieces of music with varying levels of morphological fluctuation were notated, composed and subsequently measured to assess their morphological complexity. Perceptual tests were conducted against these compositions to examine the relationships between morphological complexity and listener preference and understanding of electroacoustic music. Results demonstrated that the inclusion of intricate patterns and fluctuations within the stimuli significantly enhanced their aesthetic appeal and emotional impact on the listeners. There were strong positive correlations between stimulus complexity and measures of preference, complexity, interest, and completeness. The findings emphasize the significance of morphological fluctuation in influencing listener preferences and experiences, highlighting the importance of incorporating morphological features in notation systems and subsequent compositions. This research has practical implications for composers, performers, and educators, demonstrating the principles of spectromorphology for creating expressive and captivating musical compositions.

Background

Advancements in technology have revolutionized the field of electroacoustic music, enabling composers to manipulate sonic events with unprecedented precision and complexity. This heightened manipulation of sound has profound implications for the morphological properties of electroacoustic compositions (Smalley, 1986; 1996; 1997). Understanding the intricate relationships between compositional intent, technological complexity, and the subsequent perceptual understanding of intentional morphology presents a unique set of analytical challenges for researchers (Young 2004). Existing studies on morphological articulation in electroacoustic music have primarily focused on separate studies of musicological discourse (see Smalley 1996; 1997, Emmerson & Landy 2016, Blackburn 2011), aural interpretation (Young 2004, (Harrison 2013) and acoustic structure (Dean and Bailes 2011; 2012). Rarely are the methodologies of Smalley's morphology and acoustic structural analysis considered together.

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Spectral, structural, timbral and spatial structures have been determined to influence listener experience (see Bailes & Dean 2007; 2011, McAdams, Douglas and Vempala 2017, Caclin et al., 2005, Barthet et al., 2010, Juslin and Laukka 2004), though little attention has been paid to understanding listener experience to varying degrees of morphological complexity in compositional settings. Higher rates of morphology are closely linked to increased listener enjoyment, particularly in the context of short morphological cues, positively impacting the subjective experiences and understandings of listeners (Cross, in review a; Cross in review b). Similarly, the inclusion of intricate patterns and fluctuations within brief cues has been found to significantly enhanced the aesthetic appeal and emotional impact on the listeners (Schubert 2013). The next challenge is to create empirical evidence that illustrates how morphological articulation affects listener experience. Representing and communicating morphological ideas effectively poses a significant challenge to composers. Without the ability to measure the value of morphology in electroacoustic music, the understanding and interpretation of morphology remain subjective. The subjective nature arises from the reliance on individual perception and interpretation, rather than objective and quantifiable measures. As a result, different composers and listeners may have varying conceptions of morphology (Blackburn 2010; Dunkelman 1995 cited in Couprie 2011; Berquin 2011; Boulez in Merlier 2011), making it challenging to establish a consistent understanding and analysis of morphological complexities in electroacoustic music. Cross (in press) expanded upon Blackburn's graphic symbols and annotations of sound-shapes for a series of analyses, introducing the concept of a standardised calculated value to depict the size, complexity, and density of a sound-shape (see Figure 1). By linking this standardised notational system of morphology to subsequent acoustic analyses and perceptual testing, we become able to draw parallels between morphological fluctuation and the perceptual impacts on listener experience and understanding, and subsequently, what these impacts mean for future avenues of electroacoustic notation and composition.

This paper addresses these challenges through proof of concept, combining the above methodologies to prove the interconnectedness of morphology in electroacoustic compositions and their positive impacts on listener enjoyment, understanding and interest. Building upon the existing literature on the complexity of morphological notation in music (Blackburn 2011; Nystrom 2011), this study goes beyond existing analyses of short stimuli (see Cross, in review a; in review b) and explores the interconnectedness between long-form electroacoustic compositions and their morphological structures. By examining longer-form compositions, this study will uncover nuanced temporal and structural variations that are not readily discernible in shorter excerpts. Smalley's morphology provides a framework for understanding the structural organization and development of electroacoustic compositions. On the other hand, acoustic structural analysis explores the spectral and spatial properties of sound and their impact on the overall perception of a composition. These two analytical approaches offer complementary perspectives on the morphological complexity of electroacoustic music. By considering both the macroscopic structure and the microscopic spectral and spatial characteristics of electroacoustic compositions, researchers can gain a more comprehensive understanding of the affective embedding of morphological intent in composition.

This study proposes four hypotheses relating to the complexity of spectral (H1), spatial (H2), temporal (H3) and amplitude (H4) morphology. The first hypothesis is that listener preference and interest are influenced by the spectral complexity of electroacoustic music, in terms of gesture, motion, structure, texture and density. A second hypothesis is that listener preference and interest are influenced by the spatial complexity of electroacoustic music, in terms of gesture, motion, structure, texture and density. A third hypothesis suggests that higher levels of amplitude complexity result in greater preference, interest and presumed completeness of stimuli. The fourth hypothesis suggests that higher levels of temporal morphology will positively correlate to listeners' perceptual preference, interest and assumed completeness of auditory stimuli. These hypotheses provide a framework for examining the relationship between different morphological aspects and listener perception and preference. By investigating these relationships, the study aims to deepen our understanding of how specific morphological complexities contribute to the listener experience in electroacoustic music.

Method

Study Design

The study design employed in this research is a correlational study to explore the relationship between morphological complexity in electroacoustic music compositions and listener responses. Part 1 of the research paper focused on stimuli creation and composition development. A comprehensive notational system was developed to capture the spectral, spatial, temporal, and amplitude morphologies of electroacoustic music. This enhanced notation allowed for a precise representation of the morphological intricacies of the music, emphasizing complexity and fluctuation. Five morphologically complex scores were created based on this system, each having a simpler counterpart. These scores were used to create ten electroacoustic compositions, where sonic manipulations were applied to increase complexity in specific areas. The goal was to explore the relationship between larger morphologies and listener preference in longer electroacoustic pieces. Part 2 involved perceptual testing with 40 participants to assess listener responses to the stimuli. Participants rated their preferences, complexity, completeness, and interest for each stimulus using a 7-point Likert scale. Participants actively engaged with the musical stimuli and provided their subjective responses and perceptions. The collected responses were analysed using Spearman coefficient correlation models tests to identify significant trends in listener preferences and assess the relationship between listener responses and stimuli structure.

Part 1: Stimuli Creation

Spectral complexity was notated using the frequential scale, employing specific symbols or annotations to capture variations in spectral characteristics (see Figure 2). For the spatial dimension, a cartesian co-ordinate scoring system was used, deconstructing space into visual elements that conveyed the spatial properties of the sound (see Figure 2). Time and dynamics were also incorporated into these notational values, ensuring the inclusion of temporal fluctuations and amplitude variations. By integrating these elements into electroacoustic notation, a comprehensive visual representation that effectively conveys the morphological intricacies of the music becomes available. This enhanced notation allowed for a more precise and nuanced interpretation of the composition, intentionally emphasising the embellishment of morphological fluctuation and complexity in each sound cue. This notational system dictates the complexity of sound by high levels of density, movement, texture and intricacy in score (see Figure 3). This allowed for the visual representation and communication of the larger morphologies and higher spectral complexity to performers and listeners. The next challenge is to understand how listeners respond to morphological fluctuation and complexity longer forms of electroacoustic music.

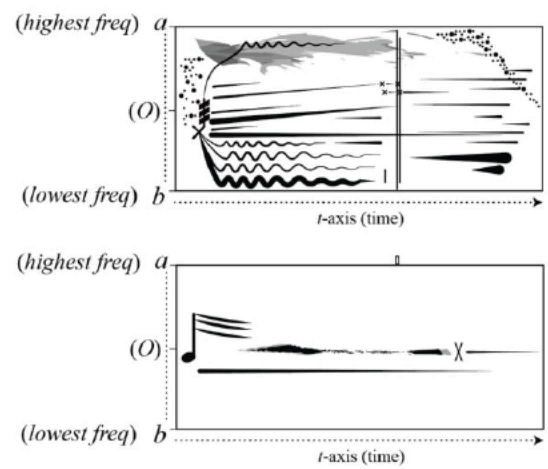


Figure 1. Frequential Fluctuation

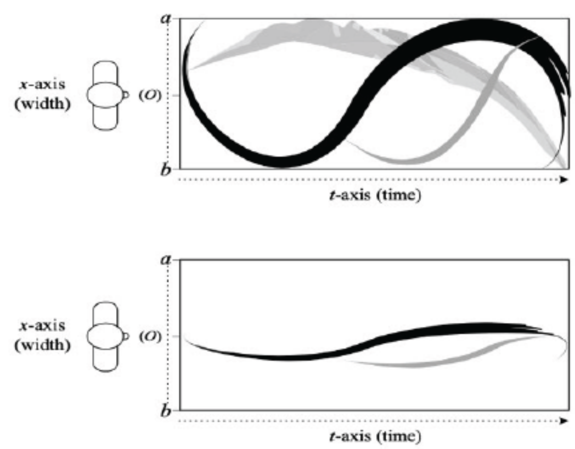


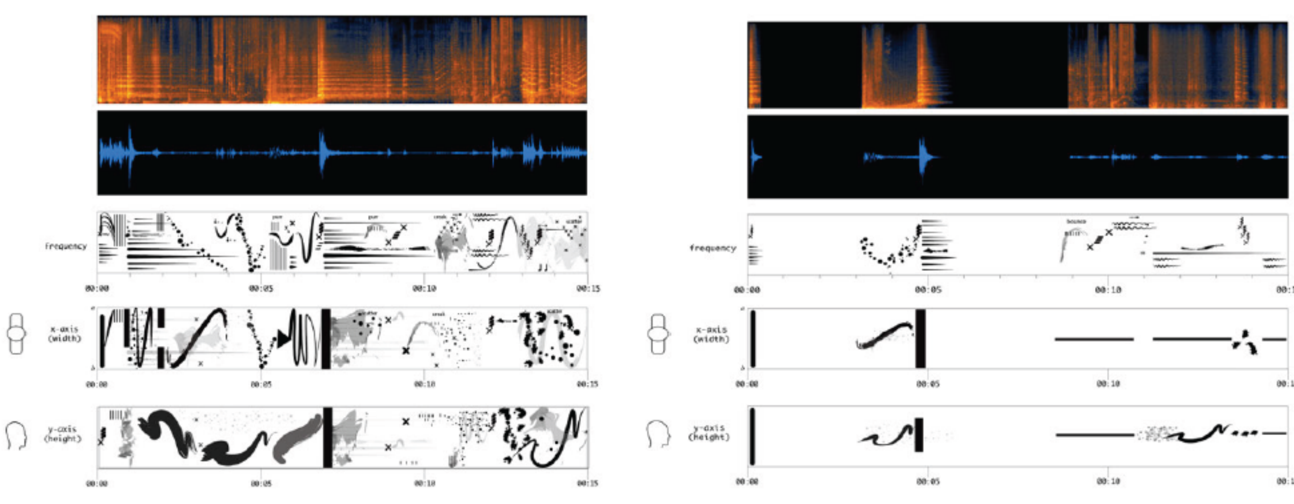
Figure 2. Spatial Fluctuation

Composition Development

Based upon the above system, five electroacoustic pieces of music were notated based upon the morphological complexities outlined in Figure 1. These scores were then intentionally given reductions and embellishments (see Figure 3) in morphological complexity, resulting in a series of 5 morphologically complex scores, with 5 simpler counterparts. These scores were used to create ten electroacoustic compositions. Each complex composition shared the same foundational morphologies of its simpler counterpart, before being added to, to adhere to the complexity of the score provided (Figure 3). While the core spectral, spatial and temporal features remained the same, complex versions included a series of sonic manipulations to force higher rates of complexity in areas of spectral structure, spectral gesture, temporal structure, amplitudinal structure, spatial texture and spatial gesture. The length of each composition was 30.00 seconds in duration, with examples of acoustic modification highlighted in Table 1. Excerpts of Composition A and Composition B are provided here as a case study (media Composition A, Composition B). This musical composition portfolio involved asystematic approach of combining the complexities of each feature outlined in Figure 1, aiming to explore the relationship between larger morphologies and listener preference in longer electroacoustic pieces (see Figure 3).

Morphology	Audio Processing Techniques
Spectral	Granular Texture, Spectral Manipulation, Microtonal Tuning, Timbral Intricacy, Frequential Oscillation, Spectral Layering
Spatial	Spatial Motion, Localisation, Spatial Complexity, Spatial Texture, Depth / Immersion, Balance / Imbalance, Fullness
Temporal	Dynamic Shaping, Articulation Variations, Accentuation, Subjective Loudness
Amplitude	Temporal Density, Syllable Density, Rhythmic Patterns

Table 1. Examples of the morphological fluctuations scored for analysis.



Composition 5 Composition 6

Figure 3. Combined notational score, detailing spectral, spatial, temporal and amplitude morphologies. Composition 1 (Left) is more morphologically intricate in notation and composition than Composition 2 (Right).

Analysis of Stimuli Complexity

To assess the morphological complexity of the sound stimuli, various methods were employed, focusing on spectral, structural, and spatiomorphological characteristics. Acoustic property analysis (Table 2) examined features such as spectral structure fluctuation, spectral motion, spatial fluctuation, temporal fluctuation, and amplitude fluctuation.

Part 2: Perceptual Study

Participants

Perceptual tests were conducted to test each hypothesis, involving 40 participants with varying proficiency in computer music (age range: 20-52; median: 34). Most participants (75%) self-identified as having musical ability, while 63% considered themselves proficient in computer music theory and/ or composition. All participants identified as having no known hearing impairments. Participants self-identified their musical abilities, ranging from high to very little musical ability. The study disregarded the impact of sex and gender on the perceptual studies based on previous findings.

Materials

The ten compositions from Part 1 of this paper were used in perceptual preference tests.

Procedure

The institutional human research ethics committee approved the project. Participants were provided with detailed information about the research before giving informed consent. The listening sessions, conducted virtually due to COVID-19 restrictions, were designed to assess listener preference, selectivity, and understanding of the complexity and fluctuation within 30-second musical pieces. The sessions were facilitated using the REDCap online survey application, which allowed for efficient management of the survey and data collection process. Participants, who were selected based on their interest and familiarity with computer music, actively engaged with the musical stimuli during the sessions. The majority of listeners (85%) used headphones, while the rest listened without headphones. To minimise bias, the cues were randomised in presentation order for each participant. Additionally, within each pair of cues, the order of presentation (Sound A or Sound B) was also randomised, ensuring fresh perceptual judgment for each comparison. Each of the ten queues indicated above were presented in pairs, at which point participants completed a questionnaire to capture their subjective responses and perceptions. Participants were instructed to compares sounds in each pairing and answer questions on a scale of 1-7 regarding their preference, perceived complexity, interest, and completeness.

Morphology	Acoustic Property
Spectral Structure Fluctuation	Acoustic Richness, Frequential Range, Harmonic Height, HNR, Spectral Centroid, Spectral Centroid Standard Deviation (σ), Spectral Flatness, Spectral Kurtosis, Spectral Skewness
Spectral Motion, Gesture & Fluctuation	Feature-Based Flux, Harmonic Energy (Timbre), Novelty (SSM), Peak Frequency (σ), Spectral Flux, Spectral Slope
Spatial Fluctuation	Diffspec, Simspec, Spatial Flux
Temporal Fluctuation	High Temporal Index (Ht), Continuous Spectral Entropy, Envelope Median (M) Power Density Spectrum (Median & Range), Syllable Density, Zero Crossing
Amplitude Fluctuation	Amplitude (σ), Amplitude Envelope, Roughness (including Median measurements), Subjective Loudness

Table 2. The spectral, spatial, temporal and amplitude fluctuations analysed within this study.

Perceptual Test Analysis

The collected responses, totalling 1600, were investigated to identify significant trends in listener preferences for electroacoustic structure and sound characteristics, particularly focusing on morphological fluctuation. Spearman coefficient correlation models were employed to examine the relationship between listener response and stimuli structure, with a specific emphasis on morphological fluctuation. Supplementary model testing using Eta squared readings and Pearson Chi Squared tests were conducted to further refine the analysis and assess statistical significance.

Results

Part 1: Stimuli Complexity

Significant differences in complexity were observed among the stimuli (Table 3 - 5). Notably, compositions 1, 3, 5, 7, and 9 demonstrate greater spectral complexity, higher temporal variability, broader frequency distribution, and more pronounced peak values. In Table 3 (Categorised measurements of spectral fluctuation and morphology), there is a consistent pattern where compositions 1, 3, 5, 7 and 9 held higher rates of spectral fluctuation and complexity within their respective pairings (indicated by larger values in features such as feature-based flux, spectral centroid, spectral flux, harmonic height, frequential range, and continuous spectral entropy). In Table 4 (Categorised measurements of spatial and temporal fluctuation), a similar trend can be observed. Compositions 1, 3, 5, 7 and 9 held higher rates of spatial and temporal fluctuation and complexity (indicated by larger values in measurements such as spectral texture, simspec, difspec, high temporal index, syllable density, and acoustic richness). Similarly, in Table 5 (Categorised measurements of amplitude fluctuation), compositions 1, 3, 5, 7 and 9 demonstrated higher rates of amplitude complexity (indicated by larger values in amplitude dynamics, envelope parameters and loudness). These findings provide strong evidence to support the assertion that compositions 1, 3, 5, 7, and 9 are indeed more complex in terms of their acoustic properties when compared to compositions 2, 4, 6, 8, and 10.

Part 2: Perceptual Study Results

Spectral Fluctuation

Significant correlations were observed between the analysis of spectromorphological structure features and listener preferences and responses (Table 6). Acoustic Richness showed strong positive correlations with preference ($r = .738^{**}$, $p < .001$), complexity ($r = .740^{**}$, $p < .001$), interest ($r = .727^{**}$, $p < .001$), and completeness ($r = .772^{**}$, $p < .001$), indicating that a rich acoustic spectrum enhances the overall musical experience. Frequential Range (0-200 Hz) showed weak negative correlations ($r = .-137^{**}$ (μ)), suggesting that the spectral fluctuation of lower frequencies holds little impact among listeners. Contrary to this, broad frequential ranges (2-22 kHz; Overall) exhibited significant positive correlations against all four categories, highlighting the importance of a broad frequency spectrum in enhancing the perceived quality and complexity of the music.

Harmonic Height demonstrated notable positive correlations, emphasising the significance of a strong presence of harmonics in creating an engaging musical experience, while HNR (Harmonic-to-Noise Ratio) showed steady, moderate negative correlations ($r = -.369^{**}$(μ), $p < .001$), emphasising that maintaining a balance between harmonics and noise is crucial for a favourable perception. Spectral Centroid demonstrated strong positive correlations across all categories ($r = .713^{**}$ (μ)), suggesting that a concentration of spectral energy towards higher frequencies enhances the overall appeal (see Table 6). Spectral Flatness and Spectral Skewness exhibited moderate negative correlations ($r = -.463^{**}$ (μ) and $r = -.464^{**}$ (μ) respectively) highlighting the importance of a balanced and symmetrical distribution of spectral energy for a positive perception.

Correlations of spectral fluctuation (Table 7) were led by feature-based flux ($r = .693^{**}$ (μ)) and harmonic energy ($r = .678^{**}$ (μ)), which each displayed extremely high positive correlations with preference, complexity, interest, and completeness.

Pair	Composition	Feature-Based Flux	Spectral Centroid	Spectral Flux	Harmonic Height	Frequential Range	Continuous Spectral Entropy
A	1	0.08	5806	5501	3.69	13280	6247
	2	0.06	2517	2693	3.57	6098	3131
B	3	0.07	1137	10610	4.01	2508	11323
	4	0.05	797	9778	2.24	1716	10362
C	5	0.07	5050	1115	3.15	10992	4574
	6	0.04	3092	3919	2.58	8074	1429
D	7	0.08	857	38974	4.59	1782.	40074
	8	0.04	809	23142	4.15	1762	23841
E	9	0.05	869	5607	2.63	2115	5995
	10	0.05	505	2038	2.59	1130	2233

Table 3. Categorised measurements of spectral fluctuation and morphology

Pair	Composition	Spectral Texture	simspec	difspec	High Temporal Index	Syllable Density	Acoustic Richness
A	1	1	54.18	0.32	0.96	55	1
	2	-1	68.8	0.04	0.91	46	0.25
B	3	1	56.78	0.26	0.97	12	1
	4	-1	69.66	0.03	0.96	9	0.25
C	5	1	54.83	0.29	0.95	61	1
	6	-1	69.36	0.18	0.88	53	0.25
D	7	1	56.64	0.3	0.99	41	1
	8	-1	66.66	0.06	0.97	66	0.25
E	9	1	56.81	0.29	0.96	40	1
	10	-1	59.19	0.15	0.92	15	0.25

Table 4. Categorised measurements of spatial and temporal fluctuation

Pair	Composition	Amplitude Envelope (000,000)	Amplitude Envelope Median	Dynamics (ampl_sd)	Loudness	Median of the Envelope (M)
A	1	824	0.034	0.022	7.403	0.069
	2	286	0.002	0.013	1.794	0.004
B	3	486	0.014	0.01	3.45	0.028
	4	321	0.008	0.012	1.872	0.016
C	5	632	0.007	0.023	5.826	0.014
	6	199	0.001	0.016	0.708	0.001
D	7	3364	0.07	0.015	6.475	0.139
	8	1254	0.027	0.014	3.318	0.053
E	9	889	0.011	0.033	2.535	0.022
	10	4486	0.002	0.018	0.785	0.004

Table 5. Categorised measurements of amplitude fluctuation

	Preference (r)	Complexity (r)	Interest (r)	Completeness (r)	Averages (r)	Effect Size
Acoustic Richness	.738**	.740**	.727**	.772**	.744**	High
Frequential Range (0 - 200 Hz)	-152**	-095**	-135**	-166**	-137**	Low
Frequential Range (2 - 22 kHz)	.662**	.577**	.627**	.671**	.634**	High
Frequential Range (Overall)	.695**	.673**	.673**	.719**	.690**	High
Harmonic Height	.639**	.638**	.631**	.679**	.647**	High
HNR (Harmonic-to-Noise Ratio)	-346**	-402**	-363**	-367**	-369**	Med
Spectral Centroid	.727**	.685**	.698**	.744**	.713**	High
Spectral Centroid Standard Deviation (σ)	.476**	.431**	.442**	.467**	.454**	Med
Spectral Flatness	-427**	-519**	-448**	-457**	-463**	Med
Spectral Kurtosis	.314**	.168**	.254**	.269**	.251**	Low
Spectral Skewness	-433**	-507**	-452**	-463**	-464**	Med

**. Correlation is significant at the 0.01 level (1-tailed).

Table 6. Spearman Correlation Coefficient of Spectral Structure

This suggests that the presence of higher harmonic energy in the timbre contributes to enhanced listener preferences and perceived complexity and interest. Novelty, measured by the Self Similarity Matrix, showed weak negative correlations, indicating that higher predictability may have a negative impact on preferences (r = -.234**) and complexity (r = -.267**) perceptions. Peak Frequency variability had a slight positive correlation with preference (r = -.224) but weak and non-significant correlations with complexity, interest, and completeness, suggesting that greater variability in peak frequency contributes slightly to listener preferences.

Spectral Entropy exhibited significant positive correlations, while Spectral Entropy variability showed moderate negative correlations with preference, complexity, interest, and completeness. Although the correlations are moderate, they indicate that higher variability in spectral entropy might decrease listener preferences, complexity perceptions, and interest levels. These findings suggest that incorporating spectral flux in music composition positively influences listener preferences and perceptions of complexity and interest. Spectral Slope displayed weak and statistically non-significant correlations with preference (r = -.004, p = .945), complexity (r = .185, p < .001), interest (r = .063, p = .229), and completeness (r = .058, p = .262). Therefore, the spectral slope does not seem to have a significant impact on listener preferences, complexity perceptions, interest levels, or completeness judgments.

Spatial Fluctuation

Diffspec showed significant positive correlations with preference (r = .623, p < .001), complexity (r = .642, p < .001), interest (r = .618, p < .001), and completeness (r = .663, p < .001). These findings indicate that incorporating spatial complexity positively influences listener preferences, complexity perceptions, interest levels, and judgments of completeness (see Table 8). Similarly, the feature simspec exhibited significant negative correlations with preference (r = -717, p < .001), complexity (r = -655, p < .001), interest (r = -683, p < .001), and completeness (r = -731, p < .001). These results demonstrate that higher levels of simspec, representing reduced spatial fluctuation, negatively impacting listener preferences, complexity perceptions, interest levels, and completeness judgments. Overall, the analysis demonstrates that spatial flux, as represented by diffspec and simspec, significantly influences listener preferences, complexity perceptions, interest levels, and judgments of completeness. The findings emphasise the importance of incorporating spatial variations and complexities in music composition to enhance the listeners' perception of immersion, realism, and complexity.

Spatial Fluctuation

The results of continuous spectral entropy indicate a significant positive correlation with preference,

	Preference (r)	Complexity (r)	Interest (r)	Completeness (r)	Averages (r)	Effect Size
Feature-Based Flux	.691**	.675**	.678**	.723**	.693**	High
Harmonic Energy (Timbre)	.673**	.677**	.661**	.702**	.678**	High
Novelty (Self Similarity Matrix)	-234**	-267**	-246**	-242**	-247**	Low
Peak Frequency Standard Deviation (σ)	.224**	.080 (p = .125)	.179**	.202**	.171**	Low
Spectral Entropy	.695**	.673**	.673**	.719**	.690**	High
Spectral Entropy Standard Deviation (σ)	-625**	-646**	-626**	-673**	-642**	Med
Spectral Flux	.665**	.686**	.662**	.707**	.680**	High
Spectral Slope	-004 (p = .945)	.185**	.063 (p = .229)	.058 (p - .262)	.075 (p = .359)	Low

**. Correlation is significant at the 0.01 level (1-tailed).

Table 7. Spearman Correlation Coefficient of Spectral Motion, Gesture & Fluctuation

	Preference (r)	Complexity (r)	Interest (r)	Completeness (r)	Averages (r)	Effect Size
diffspec	.623**	.642**	.618**	.663**	.637**	High
simspec	-717**	-655**	-683**	-731**	-.697**	High
Spatial Flux	.738**	.740**	.727**	.772**	.744**	High

**. Correlation is significant at the 0.01 level (1-tailed).

Table 8. Spearman Correlation Coefficient of Spatial Structure, Motion & Texture.

suggests that as the spectral entropy increases, there is a greater likelihood of higher preference, perceived complexity, interest, and completeness in the music. Higher spectral entropy values indicate a greater variation and diversity in the spectral content of the music, which appears to be associated with more positive evaluations by listeners in terms of preference, complexity, interest, and perceived complete. High Temporal Index (HT) exhibited strong positive correlations with preference ($r = .762$, $p < .001$), complexity ($r = .704$, $p < .001$), interest ($r = .730$, $p < .001$), and completeness ($r = .774$, $p < .001$). These findings indicate that higher values of HT, representing increased temporal complexity, are associated with greater preference, perceived complexity, interest, and judgments of completeness.

Median of the Envelope (M) also displayed significant positive correlations with preference (r = .742** (µ)), suggesting that the variation and shape of the envelope play a pivotal role in shaping listener perceptions. Higher median values of the envelope are associated with increased preference, perceived complexity, interest, and judgments of completeness. Therefore, carefully crafting and manipulating the envelope can contribute to the overall quality and impact of the musical experience. Power Density Spectrum (PSD) (Median) showed a significant negative correlation with preference (r = .-690** (µ)), indicating that a higher median value in the power density spectrum, representing greater spectral concentration, is associated with decreased preference, perceived complexity, interest, and judgments of completeness.

PSD (Range) demonstrated a moderate positive correlation with preference ($r = .405$, $p < .001$) and complexity ($r = .332$, $p < .001$), suggesting that a broader range of frequencies contributes to the perception of higher preference and complexity. This indicates that incorporating a wide frequency range can add depth and richness to the musical composition. Syllable Density exhibited a significant positive correlation (r = .-601 (µ)), indicating that more rhythmic and temporal variations are associated with increased preference, perceived complexity, interest, and judgments of completeness. Therefore, incorporating diverse syllabic patterns and rhythmic structures can enhance the overall musical experience. Finally, Zero Crossing displayed a significant positive correlation with preference (r = .423, p < .001), complexity (r = .365, p < .001), interest (r = .400, p < .001), and completeness (r = .429, p < .001). This indicates that a higher number of zero crossings, reflecting more rapid changes in the audio signal, is associated with increased preference, perceived complexity, interest, and judgments of completeness.

Amplitude Fluctuation

Amplitude (SD) showed moderate positive correlations with preference (r = .516, p < .001), complexity (r = .456, p < .001), interest (r = .492, p < .001), and completeness (r = .522, p < .001). These findings suggest that a greater variability in amplitude contributes to increased preference, perceived complexity, interest, and judgments of completeness (see Table 10). Incorporating dynamic changes in amplitude can enhance the overall appeal and engagement of the listeners. Amplitude Envelope displayed strong positive correlations with preference (r = .749, p < .001), complexity (r = .691, p < .001), interest (r = .719, p < .001), and completeness (r = .765, p < .001). This indicates that the shape and variation of the amplitude envelope significantly influence listener perceptions. Higher values of the amplitude envelope are associated with increased preference, perceived complexity, interest, and judgments of completeness.

Roughness exhibited a significant negative correlation with preference (r = -265, p < .001), complexity (r = -385, p < .001), interest (r = -302, p < .001), and completeness (r = -327, p < .001). This suggests that higher levels of roughness, indicating a more dissonant or noisy texture, are associated with decreased preference, perceived complexity, interest, and judgments of completeness. Minimising excessive roughness can contribute to a more pleasant and coherent listening experience. Roughness (Median) displayed a moderate positive correlation with preference (r = .396, p < .001), complexity (r = .507, p < .001), interest (r = .423, p < .001), and completeness (r = .432, p < .001). This indicates that a moderate level of roughness, represented by the median value, is associated with increased preference, perceived complexity, interest, and judgments of completeness. Subjective Loudness exhibited strong positive correlations with preference (r = .762, p < .001), complexity (r = .704, p < .001), interest (r = .730, p < .001), and completeness (r = .774, p < .001). These findings suggest that higher subjective loudness levels positively influence listener preferences, complexity perceptions, interest levels, and judgments of completeness.

	Preference (*r*)	**Complexity (*r*)**	**Interest (*r*)**	**Completeness (*r*)**	**Averages (*r*)**	**Effect Size**
Continuous Spectral Entropy	.768**	.725**	.736**	.778**	.751**	High
High Temporal Index (HT)	.762**	.704**	.730**	.774**	.742**	High
Median of the Envelope (M)	.746**	.685**	.713**	.760**	.726**	High
Power Density Spectrum (Median)	-695**	-673**	-673**	-719**	-.690**	High
Power Density Spectrum (Range)	.405**	.332**	.375**	.412**	.381**	Med
Syllable Density	.602**	.601**	.583**	.616**	.601**	High
Zero Crossing	.423**	.365**	.400**	.429**	.404**	Med

**. Correlation is significant at the 0.01 level (1-tailed).

Table 9. Spearman Correlation Coefficient of Temporal Flux

	Preference (r)	Complexity (r)	Interest (r)	Completeness (r)	Averages (r)	Effect Size
Amplitude (SD)	.516**	.456**	.492**	.522**	.497**	Med
Amplitude Envelope	.749**	.691**	.719**	.765**	.731**	High
Roughness	-265**	-385**	-302**	-327**	-.320**	Med
Roughness (Median)	.396**	.507**	.423**	.432**	.439**	Med
Subjective Loudness	.762**	.704**	.730**	.774**	.743**	High

**. Correlation is significant at the 0.01 level (1-tailed).

Table 10. Spearman Correlation Coefficient of Amplitude Flux

Discussion

Overall, the results suggest that variations in amplitude, spatial distribution, spectral content, and temporal characteristics significantly contribute to the overall appeal, perceived complexity, interest, and judgments of completeness in music (see Table 11). Amplitude fluctuations held a moderate positive association with preference, complexity, interest, and completeness. This suggests that greater variability in amplitude contributes to a more favourable perception of music in terms of preference, complexity, interest, and completeness. Spatial fluctuation features exhibit strong positive correlations with preference, complexity, interest, and completeness. This indicates that the spatial characteristics of music, such as the distribution and movement of sound across the stereo field, significantly influence listener responses and judgments. Spectral features show positive associations with preference, complexity, interest, and completeness. This implies that the spectral content of music, including aspects like frequency range and energy distribution, plays a role in shaping listener responses and judgments. Temporal features demonstrate positive correlations with preference, complexity, interest, and completeness. This suggests that the temporal characteristics of music, such as variations in timing, rhythm, and envelope, significantly influence listener responses and judgments.

All four hypotheses were supported by the findings to varying degrees, with results indicating that the incorporation of diverse and dynamic morphological elements in music composition and notation, including spectral, spatial, amplitude, and temporal complexities, significantly impacted listener preference, interest, and perceived completeness. The positive correlations observed between various acoustic properties and complexity measures suggest that incorporating specific features in the music notational system can enhance the perceived complexity of the music. For instance, acoustic properties such as spatial fluctuation, spectral variations, and temporal fluctuations play significant roles in shaping the complexity of musical stimuli.

Spectromorphological fluctuation emerged as a pivotal factor in influencing listener preference and experience. In line with Hypothesis 1, results reinforced the importance of spectral complexity in electroacoustic music composition and notation. The positive correlations between preference, complexity, interest, and completeness with features such as Feature-Based Flux, Harmonic Energy (Timbre), and Spectral Entropy provide direct evidence of the impact of diverse and dynamic spectral characteristics on listener engagement and satisfaction. These strong correlations align with previous studies (Caclin et al. 2005; Barthet et al. 2010) emphasising the significance of incorporating diverse and dynamic spectral characteristics, such as gesture, motion, structure, texture, and density, in music composition and notation, to enhance listener engagement and satisfaction. The findings of spectral gesture analysis specifically highlight the significance of composing with higher levels of spectral fluctuation. Furthermore, the presence of novelty in spectral gesture, along with the moderate influence of peak frequency standard deviation and spectral slope, suggests that carefully balancing and manipulating these fluctuating elements can contribute to the overall effectiveness and impact of the composition.

	Preference (*r*)	Complexity (*r*)	Interest (*r*)	Completeness (*r*)	Averages (*r*)
Amplitude	.516**	.549**	.533**	.564**	.541**
Spatial	.693**	.679**	.676**	.722**	.693**
Spectral	.496**	.491**	.486**	.515**	.497**
Temporal	.628**	.584**	.601**	.641**	.614**

**. Correlation is significant at the 0.01 level (1-tailed).

Table 11. Spearman Correlation Coefficients of Morphological Categories ($p = <.001$).

Supporting Hypothesis 2, the study demonstrates the influence of spatial complexity on listener preferences and responses. Both diffspec and simspec, which contribute to spatial complexity, exhibited noteworthy correlations with preference, complexity, interest, and completeness. These correlations indicate that incorporating spatial variations and complexities in music composition and notation can have a profound impact on listeners' perception of immersion, realism, and complexity. The positive correlations between diffspec and the perceptual dimensions of preference, complexity, interest, and completeness underscore the importance of considering spatial fluctuation in the compositional process. Similarly, the negative correlations observed between simspec and the perceptual dimensions indicate that higher values of simspec, reflecting greater similarity in spatial patterns, are associated with increased preference, complexity, interest, and completeness. This suggests that incorporating spatial variations and complexities, as represented by simspec, can contribute to the perceived richness and intricacy of the music.

In support of Hypothesis 3, the study reveals the influence of amplitude complexity on listener preferences and responses, although with some nuanced findings. Several features, such as Amplitude (SD), Amplitude Envelope, and Subjective Loudness, exhibit positive correlations with preference, interest, and completeness, indicating the importance of amplitude dynamics in music composition and notation. These correlations suggest that carefully crafting the amplitude variations and dynamics can enhance the emotional response and perceived intensity of the music. The positive correlation between Amplitude (SD) and the perceptual dimensions of preference, complexity, interest, and completeness highlights the role of amplitude variability in capturing the listeners' attention and enhancing their engagement. Similarly, the positive correlations observed for features like Amplitude Envelope and Subjective Loudness emphasise their significance in shaping listener preferences and responses. The amplitude envelope represents the temporal changes in amplitude over time, influencing the perceived loudness and dynamics of the music, indicating that carefully manipulating the amplitude envelope can evoke emotional responses and heighten the perceived intensity of the music.

It is important to note that the presence of negative correlations, as observed for Roughness, suggests the intricate nature of amplitude complexity and its impact on listener perception. Roughness refers to the perceived dissonance or irregularity in sound, and the negative correlations indicate that excessive or inappropriate complexity in amplitude fluctuations may have a detrimental effect on listener preferences and responses. This finding underscores the importance of balanced and judicious use of amplitude complexity to ensure that it enhances the overall musical experience without overwhelming or distracting the listener. These findings align with previous research conducted by (Barthet et al. 2010), emphasising the significance of carefully crafted amplitude dynamics in music composition and notation. The results highlight the importance of understanding the intricate relationship between amplitude complexity and listener perception to effectively evoke emotional responses and shape the overall musical experience.

In support of Hypothesis 4, the study provides evidence for the positive correlation between temporal complexity and listener preferences and responses. Several features, including Continuous Spectral Entropy, High Temporal Index (HT), Median of the Envelope (M), and Syllable Density, show significant positive correlations with preference, complexity, interest, and completeness, indicating the importance of incorporating temporal variations and complexities in music composition and notation. The positive correlations observed for Continuous Spectral Entropy and High Temporal Index (HT) suggest that complexity and temporal variations and fluctuations play a crucial role in capturing listener attention and enhancing their engagement with the music. The higher the temporal index, the greater the perceived complexity and rhythmicity, contributing to positive listener responses. This finding emphasises the significance of carefully manipulating temporal elements to create expressive and rhythmically engaging musical experiences.

The study found that variations in the temporal envelope positively impact the music experience, enhancing listener engagement and enjoyment. Managing syllable density also has a positive effect on preference, complexity, interest, and completeness. These findings support previous research (see Juslin and Laukka (2004), emphasizing the importance of incorporating temporal variations and complexities in music composition and notation. Manipulating temporal elements can evoke emotional expression, enhance rhythmicity, and increase overall complexity. However, not all aspects of temporal complexity universally contribute to positive experiences, as certain features may have negative or weak correlations with listener preferences. Therefore, careful consideration and artistic judgment are necessary when incorporating temporal elements to achieve the desired emotional expression and complexity without overwhelming the listener.

The observed correlations between morphological features and perceptual dimensions emphasise the impact of complexity, flux, and intricate elements in music composition and notation on listener preference, interest, and perceived completeness. This suggests that listeners tend to be more engaged and inclined towards music that exhibits higher levels of morphological flux and complexity. Furthermore, these correlations suggest that the notational system plays a vital role in guiding composers and musicians in manipulating and communicating specific types of fluctuation in their compositions. For example, there are significant associations between spectral fluctuation and measures of preference, complexity, interest, and completeness. This implies that the notational system enables composers to accurately represent and control the spectral variations in frequency, which contribute to the perceived aesthetic qualities of music. Similarly, spatial, amplitude and temporal fluctuation measures also show significant correlations with preference, complexity, and other subjective responses, indicating that the notational system facilitates the representation and communication of spatial effects, spectral characteristics, and temporal dynamics in music. Overall, these findings highlight the pivotal role of the notational system in capturing and conveying various types of fluctuation, allowing composers to create music that aligns with their artistic intentions and elicits specific perceptual responses from listeners.

Conclusion

This study offers valuable insights into the role of morphological fluctuation in shaping listener experience, preference, and understanding. By analysing spectral, spatial, amplitude, and temporal complexities, this study has shed light on the multidimensional nature of technologically induced complexity in electroacoustic music and its impact on subjective responses. The findings emphasize the significance of morphological fluctuation in influencing listener preferences and experiences, highlighting the importance of considering these features in music composition and notation systems. Incorporating a notational system developed by Cross (in review c), which emphasizes complexity through density, movement, texture, and intricacy, this study demonstrates how visual representation of larger morphologies and higher spectral complexity can enhance listener engagement. The inclusion of longer compositions allows for a more comprehensive exploration of dynamic morphological fluctuations, enhancing the listener's perceptual experience.

These insights have practical implications for composers, performers, and researchers alike. Composers can utilise the principles of spectromorphology to create more expressive and engaging compositions by incorporating dynamic changes in spectral, spatial, amplitude, and temporal characteristics. Effective notational systems can better capture and communicate these morphological fluctuations, enhancing musical representations. Performers can interpret and convey spectral characteristics more effectively by visually conveying variations in gesture, motion, structure, texture, and density. Future research should explore the influence of morphological fluctuation in other musical contexts to provide a more comprehensive understanding. Additionally, integrating physiological and neuroimaging measures could provide further insights into the underlying mechanisms of morphological fluctuation perception. Overall, this study advances our understanding of the impact of morphological fluctuation on listener preference, experience, and understanding. By embracing and harnessing the power of morphological fluctuation, composers and researchers can continue to push the boundaries of sonic creativity and enhance the listener's journey through the ever-evolving landscape of sound.

References

Bailes, F. and Dean, R. T. 2007. Listener Detection of Segmentation in Computer-Generated Sound: An Exploratory Experimental Study. Journal of new music research 36(2): 83-93.

Bailes, F. and Dean, R. T. 2012. Comparative Time Series Analysis of Perceptual Responses to Electroacoustic Music. Music perception 29(4): 359-375.

Barthet, M., Depalle, P., Kronland-Martinet, R. and Ystad, S. 2010. Analysis-by-synthesis of timbre, timing, and dynamics in expressive clarinet performance. Music perception 28(3): 265-278.

Bailes, F. and Dean, R. T. 2007. Listener Detection of Segmentation in Computer-Generated Sound: An Exploratory Experimental Study. Journal of new music research 36(2): 83-93.

Bailes, F. and Dean, R. T. 2012. Comparative Time Series Analysis of Perceptual Responses to Electroacoustic Music. Music perception 29(4): 359-375.

Barthet, M., Depalle, P., Kronland-Martinet, R. and Ystad, S. 2010. Analysis-by-synthesis of timbre, timing, and dynamics in expressive clarinet performance. Music perception 28(3): 265-278.

Berquin, L. (2011). SISMO: Solution intégrée pour la spatialisation de sources multiphoniques orientée multipoint. LIEN: L'ESPACE DU SON III: 45-54. Blackburn, M. (2011). The Visual Sound-Shapes of Spectromorphology: an illustrative guide to composition. Organised Sound : An International Journal of Music Technology 16(1): 5-13.

Caclin, A., McAdams, S., Smith, B. K. and Winsberg, S. 2005. Acoustic correlates of timbre space dimensions: A confirmatory study using synthetic tones. The Journal of the Acoustical Society of America 118(1): 471-482.

Cross, T. (in press). Reframing sound-shapes in spectromorphological composition: notating perspectival space through spherical, euclidean and cartesian-coordinate systems, Organised Sound.

Cross, T. (in review a). Time series analyses of subjective perceptual responses to variable spectromorphological complexity in electroacoustic stimuli. Journal of New Music Research.

Cross, T. (in review b). Analysing the acoustic, perceptual and morphological correlations of spatial, temporal and amplitude complexity in electroacoustic stimuli, Music and Science.

Dean, R. T. and Bailes, F. 2011. Time Series Analysis as a Method to Examine Acoustical Influences on Real-time Perception of Music. Empirical musicology review 5(4): 152-175.

Emmerson, S. & Landy, L. (2016). Expanding the Horizon of Electroacoustic Music Analysis. Cambridge: Cambridge University Press.

Harrison, J. 2013. What I did on my holidays: The concrete and the ephemeral in acousmatic composition. Journal of music, technology and education 6(3): 311-322.

Juslin, P. N. and Laukka, P. 2004. Expression, Perception, and Induction of Musical Emotions: A Review and a Questionnaire Study of Everyday Listening. Journal of new music research 33(3):

McAdams, S., Douglas, C. and Vempala, N. N. 2017. Perception and Modeling of Affective Qualities of Musical Instrument Sounds across Pitch Registers. Frontiers in psychology 8: 153-153.Merlier, B. (2018). Space Notation in Electroacoustic Music: From Gestures to Signs. In S. B. a. J. Bresson (ed.) Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'18. Concordia University.
Nyström, E. 2011. Textons and the Propagation of Space in Acousmatic Music. Organised Sound : An International Journal of Music Technology 16(1): 14-26.
Schubert, E. 2013. Emotion felt by the listener and expressed by the music: literature review and theoretical perspectives. Frontiers in psychology 4: 837-837.
Young, J. 2004. Sound morphology and the articulation of structure in electroacoustic music. Organised sound : an international journal of music technology 9(1): 7-14.
Smalley, D. (1986). Spectro-morphology and Structuring Processes. In S. Emmerson (ed.) The Language Electroacoustic Music. London: Palgrave Macmillan UK.
Smalley, D. 1996. The listening imagination: Listening in the electroacoustic era. Contemporary Music Review 13(2): 77-107.
Smalley, D. 1997. Spectromorphology: Explaining Sound-Shapes. Organised Sound : An International Journal of Music Technology 2(2): 107-126.

6.2 Conclusion

Study 4 has shed light on the crucial role of performers in shaping the immersive sonic experience of electroacoustic music, highlighting their agency in creating captivating soundscapes. The findings of this study have not only deepened our understanding of the performer's role but have also raised important questions about the relationship between composition, performance, and the sonic result. Building upon these insights, the next Chapter (5) delves into a critical examination of an adjoining composition portfolio, which serves as a practical manifestation of the concepts explored in Study 4.

CHAPTER SEVEN

Composition Portfolio

7.1 Introduction

This composition portfolio builds upon the comprehensive analysis conducted in Study 4, integrating the correlations between sonic parameters and perceptual dimensions explored in Studies 1, 2, 3, and 4 to create electroacoustic compositions. These compositions employ various morphological categorisations to enhance preference, complexity, interest, and completeness. They demonstrate how increased notational and acoustic complexity enriches the listener's sonic experience. In the context of this portfolio, the term *complexity* is predominately used to refer to morphological *complexity* (see Definition 1.1) rather than the traditional notion of musical complexity. While traditional musical complexity might involve intricate polyphony, irregular rhythms or counterpoint, morphological complexity delves deeper into the nuanced variations and transformations that occur within the sonic fabric itself. It examines how changes in spectral content, temporal evolution, and spatial distribution shape the listeners' perceptual experiences.

The chapter provides an overview of the goals, methodologies, and artistic considerations that guided the creation of the composition portfolio. It explores additional parameters to shape the sonic character and enhance the portfolio's diversity. The analysis deepens our understanding of the relationships between sonic parameters and listener experiences. The expanded composition portfolio in Chapter 5 represents a synthesis of the findings from Study 4 (Tables 1 – 3), showcasing Compositions 1, 3, 5, 7 and 9. Progressing from the empirical findings of Study 4, the focus in this chapter shifts from data analysis to artistic exploration. The aim is to demonstrate the effective translation of acquired knowledge into compositions that embody the richness, complexity, and expressive potential of electroacoustic music.

Pair	Composition	Feature-Based Flux	Spectral Centroid	Spectral Flux	Harmonic Height	Frequential Range	Continuous Spectral Entropy
A	1	0.08	5806	5501	3.69	13280	6247
	2	0.06	2517	2693	3.57	6098	3131
B	3	0.07	1137	10610	4.01	2508	11323
	4	0.05	797	9778	2.24	1716	10362
C	5	0.07	5050	1115	3.15	10992	4574
	6	0.04	3092	3919	2.58	8074	1429
D	7	0.08	857	38974	4.59	1782.	40074
	8	0.04	809	23142	4.15	1762	23841
E	9	0.05	869	5607	2.63	2115	5995
	10	0.05	505	2038	2.59	1130	2233

Table 1: Categorised measurements of spectral fluctuation and morphology (Cross, in review c)

Pair	Composition	Spectral Texture	*simspec*	*difspec*	High Temporal Index	Syllable Density	Acoustic Richness
A	1	1	54.18	0.32	0.96	55	1
	2	-1	68.8	0.04	0.91	46	0.25
B	3	1	56.78	0.26	0.97	12	1
	4	-1	69.66	0.03	0.96	9	0.25
C	5	1	54.83	0.29	0.95	61	1
	6	-1	69.36	0.18	0.88	53	0.25
D	7	1	56.64	0.3	0.99	41	1
	8	-1	66.66	0.06	0.97	66	0.25
E	9	1	56.81	0.29	0.96	40	1
	10	-1	59.19	0.15	0.92	15	0.25

Table 2: Categorised measurements of spatial and temporal fluctuation (Cross, in review c)

Pair	Composition	Amplitude Envelope (000,000)	Amplitude Envelope Median	Dynamics (*ampl_sd*)	Loudness	Median of the Envelope (M)
A	1	824	0.034	0.022	7.403	0.069
	2	286	0.002	0.013	1.794	0.004
B	3	486	0.014	0.01	3.45	0.028
	4	321	0.008	0.012	1.872	0.016
C	5	632	0.007	0.023	5.826	0.014
	6	199	0.001	0.016	0.708	0.001
D	7	3364	0.07	0.015	6.475	0.139
	8	1254	0.027	0.014	3.318	0.053
E	9	889	0.011	0.033	2.535	0.022
	10	4486	0.002	0.018	0.785	0.004

Table 3: Categorised measurements of amplitude fluctuation (Cross, in review c)

The data obtained from both Papers 1 and 2 played a pivotal role in shaping the direction of compositional approach. The consistent trends observed across both studies where that higher rates of spectral, temporal, amplitude, and spatial complexity resulted in increased enjoyability. The specific findings relating to each morphology lead the approach of this portfolio. From the findings of paper 1, there was a focus on achieving richer harmonic content, aiming to captivate listeners with a heightened sense of spectral intricacy. From the findings of paper 2, higher temporal flux was embraced to introduce dynamic and evolving sonic elements. Spatial movement was also introduced as per the results of the second study, to create spatiomorphological structures that mirrored the preferences of survey participants.

Ultimately, this chapter serves as a critical reflection on the practical application of the research findings, providing valuable insights into the relationship between theory and practice in electroacoustic music composition. Through this critical examination, the chapter contributes to the ongoing discourse surrounding the creation and realization of immersive sonic experiences, paving the way for further exploration and development in this fascinating field. Primary compositions (1, 3, 5, 7 and 9) are presented below, alongside supplementary compositions that followed the same morphological fluctuations and compositional methods.

In addition to the primary compositions, each primary piece in the portfolio is accompanied by two supplementary compositions. These supplementary works, although distinct in musical style (varying between realms of musique concrète, electroacoustic, acousmatic and neo-classical, adhere to the same fundamental methods employed in the primary compositions. These supplementary compositions serve to demonstrate the versatility and adaptability of the survey data's influence across different musical styles, all while maintaining a commitment to the core principles of sonic complexity, spatial intricacy, and morphological expression.

7.1.1 Composition 1

Primary Composition: Composition 1 (5'18")
Supplementary Compositions: 1B. Fractal Modulations (4'39") 1C. Quantum Sequence (4'43")

Composition 1 represents an auditory extension of the concepts and ideas investigated in Papers 1 through 4. More specifically, it acts as an extended version of Stimulus 1 of Paper 4. It serves as a tangible demonstration of the morphological analyses presented in these papers, highlighting the divergent characteristics between Stimulus 1 and Stimulus 2 and their influence on listener preference, complexity, interest, and completeness. The composition capitalizes on textural and timbral exploration, employing plugins and sound manipulation techniques to generate varied and textured spectral, spatial and amplitudinal distributions across time, thereby yielding intricate and complex timbres. Furthermore, it emphasizes morphological fluctuation through techniques such as spectral flux, continuous spectral entropy, and rapid temporal variations, creating a dynamic and intricate sonic landscape. The composition showcases the malleability of sound through technological interference, as samples undergo significant transposition, augmentation, and filtering to create altered characteristics and novel structures.

The analysis comparing Stimulus 1 against Stimulus 2 reveals several significant findings (Table 4), shedding light on the distinct attributes that contribute to their sonic divergence:

Acoustic Richness: Stimulus 1 exhibits a heightened sense of acoustic richness, augmenting its allure and captivating the listener's attention.
Frequential Range: Stimulus 1 displays a narrower frequential range in lower frequencies while encompassing a broader range in the mid to high frequencies, thus influencing its depth, richness, and overall complexity.
Harmonic Height: Stimulus 1 possesses slightly heightened harmonic height, resulting in a more pronounced and structured harmonic content.

Spectral Centroid: Stimulus 1 exhibits a higher spectral centroid, channelling energy into higher frequencies and creating a brighter, more focused sound.

Spectral Flatness: Stimulus 1 demonstrates lower spectral flatness, indicating a more diverse and textured spectral distribution, thereby enhancing its complexity and arousing interest.

Spectral Flux: Stimulus 1 showcases slightly higher spectral flux, leading to more rapid changes in spectral content over time, ultimately yielding a dynamic and evolving auditory experience (see Figure 1).

Continuous Spectral Entropy: Stimulus 1 encompasses higher continuous spectral entropy, indicative of a greater degree of spectral complexity and unpredictability.

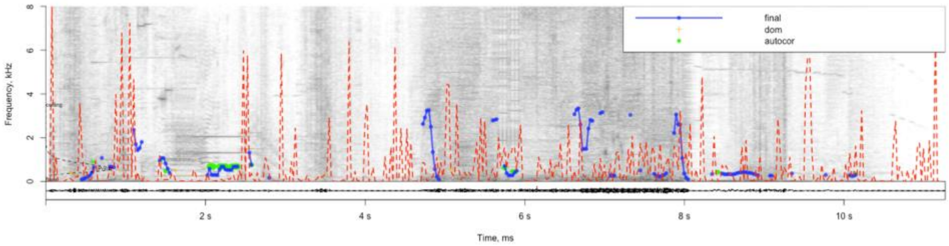
High Temporal Index: Stimulus 1 manifests a higher high temporal index, suggesting more rapid temporal fluctuations and variations, thus amplifying its dynamism.

Amplitude Envelope: Stimulus 1 possesses a more pronounced amplitude envelope, resulting in varied and impactful changes in volume, contributing to its expressiveness and engaging nature.

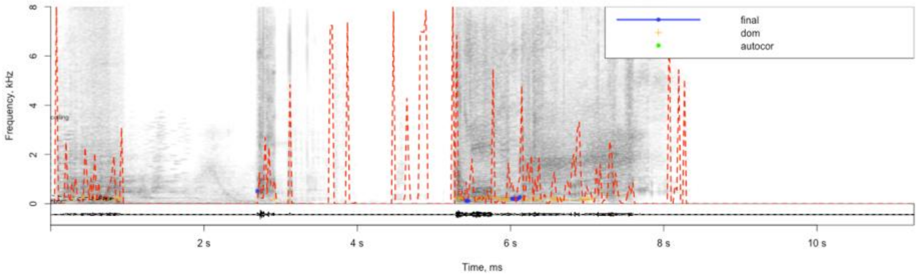
	More Preferred		**More Complex**		**More Interesting**		**More Complete**	
	Stimulus 1	Stimulus 2	Stimulus 1	Stimulus 2	Stimulus 1	Stimulus 2	Stimulus 1	Stimulus 2
Percentage of Consensus	92%	8%	92%	8%	79%	21%	82%	18%
Average Likert Rating	5.97	2.26	6.13	2.64	5.62	2.41	5.31	1.62
Likert Difference (%)	165%		132%		133%		229%	

Table 4: Likert and Consensus Results for Composition 1 (Stimulus 1) against Stimulus 2.

Overall, Composition 1 exemplifies the profound influence of morphological variations on sonic qualities and listener perception. It underscores the significance of sound design and manipulation in shaping the holistic sonic experience, as demonstrated throughout this research.



Stimulus 1



Stimulus 2

Figure 1: Difference in Dominant Spectral Flux between Stimulus 1 and Stimulus 2.

7.1.2 Composition 3

Primary Composition: Composition 3 (2'28")

Supplementary Compositions: 3B. Dusk (3'03") 3C. Astral (0'56")

Within this section, an in-depth comparative analysis of listener responses for Composition 3 (Stimulus 3) and Stimulus 4 is presented, focusing on key aspects such as preference, perceived complexity, interest, and completeness. The composition process for Composition 3 involved deliberate compositional choices aimed at enhancing its sonic attributes and complexity, drawing inspiration from orchestral music techniques. Of particular significance was the utilization of harmonic layering, which played a pivotal role in constructing morphological complexity by seamlessly blending multiple musical voices and instrumentations, resulting in the creation of rich and intricate harmonic textures. This compositional approach allowed for the exploration of complex harmonic relationships, dissonances, and tonal progressions, thereby amplifying the overall depth and complexity of the composition.

To further augment the sonic attributes, a diverse array of techniques was employed, including filters, reverbs, noise elements, delays, and echoes. The implementation of filters and granular synthesis facilitated the shaping of frequency content within individual *sound-shapes*, emphasizing clustered harmonics and spectral variations. Reverbs were utilized to imbue depth and ambience, while the addition of noise elements contributed to textural complexity. Subtle delays and echoes were employed and morphed introduce temporal, amplitudinal and rhythmic interplay, and spatial effects, ultimately intensifying the temporal and spatial and textural morphologies.

The comparative analysis conducted between Stimuli 3 and Stimulus 4 reveals noteworthy distinctions in listener responses. Stimuli 3 emerges as the clear preference, with listeners perceiving it as significantly more complex, more interesting, and more complete compared to Stimuli 4. In terms of preference, Stimuli 3 garnered a substantially higher percentage of consensus (86%) and a significantly higher average Likert rating (5.87), surpassing Stimuli 4, which received only 14% consensus and an average Likert rating of 2.97 (see Table 5). When examining perceived complexity, Stimuli 3 attained an 84% consensus rating, along with a higher average Likert rating (4.92), while Stimuli 4 received a 16% consensus and an average Likert rating of 2.10. Similarly, Stimuli 3 was deemed more interesting by listeners, with an 86% consensus rating and a higher average Likert rating (5.41), whereas Stimuli 4 achieved a 14% consensus and an average Likert rating of 2.69. Finally, regarding completeness, Stimuli 3 received an impressive 89% consensus rating and a higher average Likert rating (5.85), whereas Stimuli 4 attained only an 11% consensus and an average Likert rating of 2.21.

	More Preferred		More Complex		More Interesting		More Complete	
	Stimulus 3	Stimulus 4	Stimulus 3	Stimulus 4	Stimulus 3	Stimulus 4	Stimulus 3	Stimulus 4
Percentage of Consensus	86%	14%	84%	16%	86%	14%	89%	11%
Average Likert Rating	5.87	2.97	4.92	2.1	5.41	2.69	5.85	2.21
Likert Difference	97%		134%		101%		165%	

Table 5: Likert and Consensus Results for Composition 3 (Stimulus 3) against Stimulus 4.

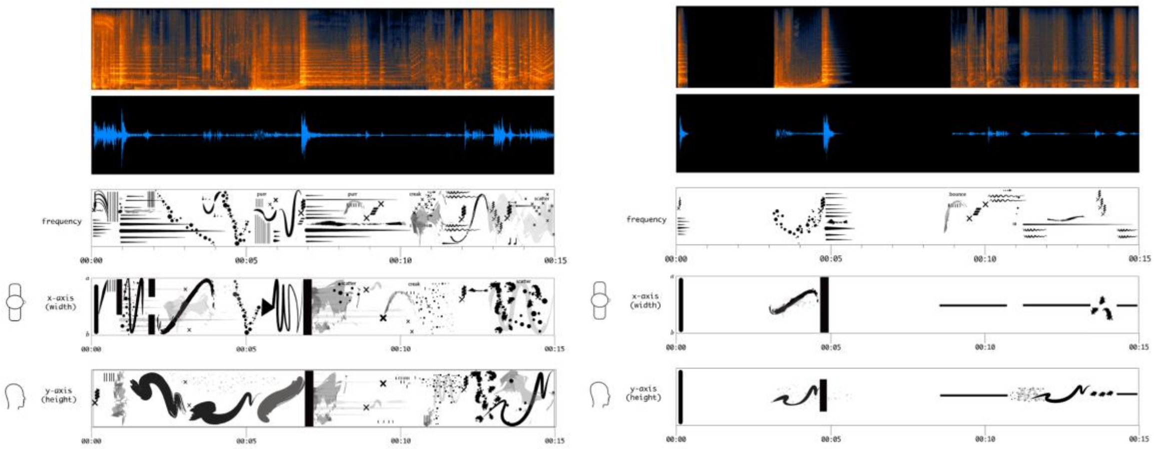
These findings underscore the impact of deliberate compositional choices, adept sound design techniques, and intentional morphological complexity on listener responses. Composition 3, with its orchestral-inspired techniques deftly mixed with deliberate fluctuation and audio manipulation, proved to be a compelling and immersive sonic experience for listeners. The results obtained from this comparative analysis deepen our understanding of the intricate relationship between compositional approaches, sonic attributes, and listener perception, thereby contributing to the advancement of electroacoustic music composition as a whole.

7.1.3 Composition 5

Primary Composition: Composition 5 (4'23")

Supplementary Compositions: 5B. Drift (4'40"), 5C. Pulses (2'55") 5D. Algorithmic Cadence (5'16") 5E. Fractures (3'37")

Composition 5 placed significant emphasis on sound design and shared similarities with Composition 1, with a particular focus on incorporating extensive abstract embellishments and morphological fluctuations into the score (refer to Figure 2). This exploration of sonic experimentation sought to create a composition rich in morphological intricacies and variations.



Composition 5 Composition 6

Figure 2: Differences in the Notation of Morphological Complexity and Fluctuation.

The comparison of Stimulus 5 (Composition 5) and Stimulus 6 reveals substantial differences in listener responses across various dimensions. Stimulus 5 was overwhelmingly preferred, perceived as significantly more complex, more interesting, and more complete compared to Stimulus 6 (Table 6). Stimulus 5 was strongly preferred by listeners (89% consensus) and perceived as significantly more complex (97% consensus) and interesting (86% consensus) compared to Stimulus 6 (11%, 3%, and 14% consensus respectively). The average Likert ratings for Stimulus 5 were higher in preference (5.38), complexity (5.82), interest (5.18), and perceived completeness (5.28) compared to Stimulus 6 (0.69, 1.41, 1.26, and 0.38 ratings respectively).

	More Preferred		**More Complex**		**More Interesting**		**More Complete**	
	Stimulus 5	Stimulus 6	Stimulus 5	Stimulus 6	Stimulus 5	Stimulus 6	Stimulus 5	Stimulus 6
Percentage of Consensus	89%	11%	97%	3%	86%	14%	95%	5%
Average Likert Rating	5.38	0.69	5.82	1.41	5.18	1.26	5.28	0.38
Likert Difference (%)	678%		313%		312%		1273%	

Table 6: Likert and Consensus Results for Composition 5 (Stimulus 5) against Stimulus 6.

Stimulus 5 consistently outperformed Stimulus 6, demonstrating higher preference, perceived complexity, interest, and completeness. Several features of Stimulus 5 (Composition 5) contribute to its preference and enjoyability compared to Stimulus 6:

Feature-Based Flux: Composition 5 exhibits a higher feature-based flux value (0.07) than Composition 6 (0.04), indicating a greater degree of spectral variability and fluctuation.
Spectral Centroid: Composition 5 has a higher spectral centroid value (5050) compared to Stimulus 6 (3092), suggesting a broader distribution of frequencies and richer tonal characteristics.
Spectral Flux: Composition 5 demonstrates a lower spectral flux value (1115) compared to Stimulus 6 (3919), implying smoother and more gradual changes in spectral content.
Harmonic Height: Composition 5 possesses a higher harmonic height value (3.15) compared to Stimulus 6 (2.58), indicating a greater presence of harmonic content and enhanced structural complexity.
Frequential Range: Composition 5 exhibits a larger frequential range value (10992.83) than Stimulus 6 (8074.72), suggesting a broader utilization of frequencies.
Continuous Spectral Entropy: Composition 5 displays higher continuous spectral entropy (4574.36) than Stimulus 6 (1429.23), implying greater morphological complexity and textural richness.
Amplitude Envelope and Dynamics: Composition 5 showcases a higher amplitude envelope value (632) compared to Stimulus 6 (199), indicating more pronounced and varied amplitude fluctuations.

7.1.4 Composition 7

Primary Composition: Composition 7 (4'13")
Supplementary Compositions: 7B. Solitude (3'27")

Composition 7 exhibits a higher spectral flux value, indicating a greater degree of spectral variability and dynamic changes in its frequency content. Additionally, it has a higher harmonic height, suggesting a richer presence of harmonic content and a more structured sound. The composition also utilizes a larger frequential range, resulting in a more diverse and expansive sonic palette. Moreover, Composition 7 demonstrates a higher continuous spectral entropy, indicating greater morphological complexity and textural richness. Lastly, it has a higher amplitude envelope value, which signifies more pronounced and varied amplitude fluctuations, creating a more dynamic and engaging sound. Collectively, these characteristics enhance the preference, enjoyability, perceived complexity, and interest of Stimulus 7 compared to Stimulus 8 (see Table 7).

Stimuli (Composition) 7 stands out among all stimuli due to its notable features. It has the highest spectral flux value, reflecting a significant degree of spectral variability and dynamic changes in its frequency content. Additionally, it possesses the highest continuous spectral entropy value, indicating a high level of morphological complexity and textural richness. Furthermore, Composition 7 exhibits the highest amplitude envelope value, emphasizing its dynamic range and expressive qualities. These features make Composition 7 distinct in terms of spectral variability, morphological complexity, and dynamic characteristics. However, there are critical notes to consider for Composition 7. Additionally, the listener responses indicate that Composition 7 was perceived as less preferred, less complex, less interesting, and less complete compared to Stimulus 8. Further analysis and exploration of the specific elements within Composition 7 could help identify areas for improvement.

	More Preferred		**More Complex**		**More Interesting**		**More Complete**	
	Stimulus 7	Stimulus 8	Stimulus 7	Stimulus 8	Stimulus 7	Stimulus 8	Stimulus 7	Stimulus 8
Percentage of Consensus	86%	14%	84%	16%	81%	19%	92%	8%
Average Likert Rating	5.62	2.95	4.95	2	5.23	2.46	5.67	1.85
Likert Difference (%)	90%		147%		113%		207%	

Table 7: Likert and Consensus Results for Composition 7 (Stimuli 7) against Stimulus 8.

7.1.5 Composition 9

Primary Composition: Composition 9 (1'42")

Supplementary Compositions: 9B. Calculations of Sorrow (2'43")

In Composition 9, there is a notable exploration of timbral qualities, particularly focused on the sonic morphologies of the prepared piano. Composition 9 effectively incorporates additional noise, space, and explores timbral qualities to enhance the nuances of the piano tones. While this offers unique sonic possibilities and creative opportunities, it is important to strike a balance between experimentation and coherence. The timbral variations of the composition enhance the palette of the piano and whilst avoiding excessive dissonance or incoherence. Composition 9 stands out among the 10 compositions due to several notable features:

> **Spectral Flux:** With a high spectral flux value of 5607, Composition 9 exhibits significant changes in spectral content over time, indicating dynamic variations in its frequency distribution.
> **Harmonic Height:** Composition 9 has a relatively high harmonic height value of 2.63, indicating a strong presence of harmonically related frequencies and a well-defined harmonic structure.
> **Syllable Density:** Composition 9 demonstrates a much higher syllable density, suggesting a rapid succession of distinct sonic events and a dense texture of sound elements.

These features contribute to the uniqueness and potential appeal of Composition 9, showcasing its strong spectral variations, harmonic content, and density of sound events. Overall, Composition 9 offers a dynamic, harmonically rich, and densely textured sonic experience. These characteristics contribute to its potential appeal, making it more preferable, enjoyable, seemingly complex, and seemingly more interesting to listeners compared to Stimulus 10. Stimulus 9 was perceived as more preferred, more complex, more interesting, and more complete compared to Stimulus 10 (see Table 8). This suggests that Stimulus 9 resonated strongly with the listeners in terms of their subjective preferences and perceptions of complexity, interest, and completeness.

	More Preferred		More Complex		More Interesting		More Complete	
	Stimulus 9	Stimulus 10	Stimulus 9	Stimulus 10	Stimulus 9	Stimulus 10	Stimulus 9	Stimulus 10
Percentage of Consensus	92%	8%	86%	14%	86%	14%	89%	11%
Average Likert Rating	5.79	2.05	5	1.26	5.49	1.92	5.51	1.23
Likert Difference (%)	183%		298%		185%		348%	

Table 8: Likert and Consensus Results for Composition 9 (Stimulus 9) against Stimulus 10.

CHAPTER EIGHT

Summary of Findings

This thesis undertook an exploration of sound-shapes taxonomy, the influence of morphological complexity on listener perception, and the implications for compositional methods in electroacoustic music. In this chapter, key findings are synthesised alongside a broader discussion regarding their implications for the field. Through these studies, this thesis has successfully answered the research questions posed in Chapter 1, demonstrating that morphological complexities encompassing spectral, spatial, temporal, and amplitude dimensions do indeed impact listener perception, preference, and understanding of electroacoustic stimuli and music. Furthermore, the thesis has elucidated the effects of morphological fluctuation and presented practical implications derived from the findings. The following summary of the key findings addresses the attainment of each research aim and the answering of research questions posed throughout the thesis.

8.1 Summary of Findings

In Study One, an investigation into the influence of spectromorphological complexity on listener preference, experience, and understanding in electroacoustic music was conducted. The findings not only corroborated all four hypotheses but also revealed the significant influence of both spectral structure and spectral flatness on listener preference and experience. The study confirmed that the complexity of a sound's spectral gesture played a substantial role in shaping listener preference, aligning with earlier research. Various acoustic properties exhibited high effect sizes, indicating spectromorphological association with complexity. Moreover, sounds featuring more harmonic information were consistently regarded as more preferred and complex by both musicians and non-musicians. The study established a positive correlation between higher levels of spectral complexity and increased preference and interest in stimuli. Notably, spectral gesture exerted a greater influence than spectral structure on listener preference. Timbral qualities, including timbral complexity and texture, also emerged as influential factors in determining listener preference. The structural composition of a sound influenced listeners' perception of complexity and completeness, with larger spectral gesture and structure leading to perceptions of greater complexity and completeness. Spectral gesture was identified as the most influential factor across preference, complexity, interest, and completeness.

Paper 2 examined the impact of spatial, amplitude, and temporal complexities on listener preference, experience, and understanding in electroacoustic music. The results supported all hypotheses, highlighting the significant effects of spatial and amplitude complexities on preference, interest, and understanding. Spatial complexity, particularly in stereophonic environments, assumed a particularly crucial role, while amplitude and temporal complexities also exhibited substantial effects. These findings align with prior research, underscoring the importance of considering morphological complexity in composition to enhance the listener experience. Overall, the study underscores the significance of spatiotemporal complexity and its implications for sound design and composition.

Study 3 laid the groundwork for comprehending the challenges and potential solutions in establishing connections between time, space, and frequency in the graphical notation of electroacoustic music. By adapting Smalley's sound-shapes and introducing a Cartesian coordinate system within the context of three-dimensional sound environments, the study enabled the notation of morphological space, time, and frequency simultaneously. This constituted a foundational exploration of spatial sound properties. The proposed method for notating sound-shapes in three-dimensional sound environments successfully addressed challenges related to spatial and spectral accuracy. Composers were empowered to plot sound shapes in morphological space, temporality, and frequency concurrently using the Cartesian coordinate system. Groupings were employed to distribute characteristics among spectral, spatial, and temporal nodes. Leveraging spatial sound properties for compositional possibilities and analysing their impact on sonic experiences represents an essential direction for future research.

Building upon the insights gained from previous studies, Study 4 delved into the correlations between various sonic parameters and perceptual dimensions. Employing Likert testing and longer-form compositions, the study explored compositional possibilities and subsequent analyses. In longer electroacoustic compositions and phrasing, variations in amplitude, spatial distribution, spectral content, and temporal characteristics were found to significantly influence overall appeal, perceived complexity, interest, and judgments of completeness in music. Incorporating diverse and dynamic morphological elements encompassing spectral, spatial, amplitude, and temporal complexities exerted a substantial impact on listener preference, interest, and perceived completeness. Spectral complexity, spatial variations, amplitude dynamics, and temporal fluctuations all played pivotal roles in shaping listener responses. The findings underscored the importance of carefully balancing and manipulating these elements to enhance the overall musical experience. The study also highlighted the role of the notational system in capturing and conveying various types of fluctuation, enabling composers to create music aligned with their artistic intentions and elicit specific perceptual responses from listeners. The practical implications derived from this study offer valuable guidance for composers, performers, and researchers, facilitating the creation of more expressive compositions and enriching musical notation.

Lastly, Chapter 5 presented an expanded composition portfolio incorporating the insights gleaned from the correlations and observations made in Study 4. This collection of compositions employed features such as feature-based flux, harmonic energy, spectral entropy, spatial flux, high temporal indices, and subjective loudness to craft engaging and immersive auditory experiences. This composition portfolio represents a culmination of analysis, artistic exploration, and the interplay between sonic parameters and perceptual trends. The findings from Studies 1 - 4 inform the artistic decisions, pushing the boundaries of creative expression in electroacoustic music. With a focus on enhancing preference, complexity, interest, and completeness, this portfolio demonstrates the intricate relationship between sound and human perception, as evident by Likert scores and listener consensus in Tables 4 - 8.

CHAPTER NINE

Conclusion and Future Directions

This thesis sheds light on various facets of electroacoustic music composition, perception, and analysis. The findings underscore the importance of morphological complexity, notation, compositional methods, and the strategic manipulation of sonic parameters in shaping listener experiences. Through the synthesis of these findings, composers and researchers possess a more comprehensive understanding of the intricate relationship between sound and perception.

The implications of the studies conducted in the field of electroacoustic music composition and perception are significant. Composers should harness the deliberate manipulation of spectral parameters to create engaging and immersive sonic environments, thereby enhancing enjoyment and interest. The adaptation of sound-shapes notation presented in Study 3 allows for more accurate representation of spatial and morphological information in three-dimensional sound environments, paving the way for future developments in spatial sound notation and analysis. The development of the notational sound system presented in this study holds immense potential for electroacoustic composition and pedagogical analysis. Composers can utilize the system to communicate complex sonic ideas, notate intricate timbral and spatial characteristics, and explore innovative sonic possibilities. In pedagogical settings, the system facilitates in-depth analysis and understanding of electroacoustic compositions, fostering critical listening skills and cross-disciplinary collaboration. Researchers can employ the standardized notation to compare compositions and study sonic aesthetics. The notational sound system represents an exciting advancement that enhances creativity, collaboration, and research in the realm of electroacoustic music. Lastly, the adjoining composition portfolio stands as evidence of how empirical research can inform and inspire creative practice in electroacoustic music.

These findings contribute to our understanding of the interplay between complexity, notation, and listener response in music composition, providing valuable insights for composers, performers, and researchers seeking to create and explore complex musical works. By embracing complexity, developing effective notational systems, and leveraging audio plugins and technologies, composers can craft rich and immersive musical experiences that resonate with audiences. This research not only contributes to theoretical and practical advancements in electroacoustic music but also encourages further exploration and experimentation in the field. To deepen our understanding, future studies can explore cross-cultural and cross-genre comparisons, objective measures of notational complexity, longitudinal studies on musical engagement, integration of multimodal stimuli, comparative analysis of notational systems, and cognitive and neuropsychological approaches. These avenues will contribute to advancing knowledge in music perception, composition, and interdisciplinary studies, fostering innovation in the field of music and technology. As the field of electroacoustic music continues to evolve, this thesis serves as a bridge towards a deeper understanding of the intricacies of sound and its impact on human perception. It is our hope that the insights gained from this research will inspire future endeavours, fostering a vibrant and dynamic landscape of electroacoustic music composition and perception.

References

Adkins, M., Scott, R., & Tremblay, P. A. (2016). Post-Acousmatic Practice: Re-evaluating Schaeffer's heritage. *Organised sound : an international journal of music technology*, *21*(2), 106-116. https://doi.org/10.1017/S1355771816000030

Alejandro Garavaglia, J. (2016). Creating Multiple Spatial Settings with "Granular Spatialisation" in the High-Density Loudspeaker Array of the Cube Concert Hall. *Computer Music Journal*, *40*(4), 79-90. https://doi.org/10.1162/COMJ_a_00384

Anderson, E. L. (2015). Space as a Carrier of Materials, Meaning, and Metaphor in Karlheinz Stockhausen's Music-Theatre Composition Sirius ((Vol. 12, pp. 259-276). transcript Verlag. https://doi.org/10.1515/9783839430767-016

Bacon, B. (2022). Rethinking the Notation Design Space. In V. T. a. J. B. a. C. d. P. Santana (Ed.), *Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'2022*.

Bailes, F., & Dean, R. T. (2007). Listener Detection of Segmentation in Computer-Generated Sound: An Exploratory Experimental Study. *Journal of New Music Research*, *36*(2), 83-93. https://doi.org/10.1080/09298210701755123

Bailes, F., & Dean, R. T. (2012). Comparative Time Series Analysis of Perceptual Responses to Electroacoustic Music. *Music perception*, *29*(4), 359-375. https://doi.org/10.1525/mp.2012.29.4.359

Bardy, F., Van Dun, B., & Dillon, H. (2015). Bigger Is Better: Increasing Cortical Auditory Response Amplitude Via Stimulus Spectral Complexity. *Ear and Hearing*, *36*(6), 677-687. https://doi.org/10.1097/AUD.0000000000000183

Barrett, N. (2016). A Musical Journey towards Permanent High-Density Loudspeaker Arrays. *Computer Music Journal*, *40*(4), 35-46. https://doi.org/10.1162/COMJ_a_00381

Barthet, M., Depalle, P., Kronland-Martinet, R., & Ystad, S. (2010). Analysis-by-synthesis of timbre, timing, and dynamics in expressive clarinet performance. *Music perception*, *28*(3), 265-278.

Berezan, D. (2011). MANTIS: Festival, Community, Sound Diffusion System and Research. In A. V. Gorne (Ed.), *LIEN: L'ESPACE DU SON III* (pp. 39-44).

Blackburn, M. (2010). Composing from spectromorphological vocabulary: proposed application, pedagogy and metadata. (Ed.),^(Eds.).

Blackburn, M. (2011). The Visual Sound-Shapes of Spectromorphology: an illustrative guide to composition. *Organised sound : an international journal of music technology*, *16*(1), 5-13. https://doi.org/10.1017/S1355771810000385

Bouwer, F. L., Burgoyne, J. A., Odijk, D., Honing, H., & Grahn, J. A. (2018). What makes a rhythm complex? The influence of musical training and accent type on beat perception. *PLoS ONE*, *13*(1), e0190322-e0190322. https://doi.org/10.1371/journal.pone.0190322

Broughton, M. C., Dimmick, J., & Dean, R. T. (2021). Affective and Cognitive Responses to Musical Performances of Early 20th Century Classical Solo Piano Compositions. *Music perception*, *38*(3), 245-266. https://doi.org/10.1525/mp.2021.38.3.245

Caclin, A., Giard, M.-H. l. n., & McAdams, S. (2009). Perception of timbre dimensions: Psychophysics and electrophysiology in humans. *The Journal of the Acoustical Society of America*, *126*(4), 2236-2236. https://doi.org/10.1121/1.3249185

Caclin, A., McAdams, S., Smith, B. K., & Winsberg, S. (2005). Acoustic correlates of timbre space dimensions: A confirmatory study using synthetic tones. *The Journal of the Acoustical Society of America*, *118*(1), 471-482. https://doi.org/10.1121/1.1929229

Chafe, C. (2018, 21 February). I am Streaming in a room. (Ed.),^(Eds.). The Power of Musical Networks, Orpheus Instituut, Ghent, Belgium.

Couprie, P. (2011). Représenter l'espace? *LIEN: L'ESPACE DU SON III*, 20-28.

Cross, T. (2018a). Neurological perception and sound-based creativity in post-biological realities: Recontextualizing reflective practice for technoetic environments. *Technoetic Arts: A Journal of Speculative Research*, *16*(1), 23-31. https://doi.org/10.1386/tear.16.1.23_1

Cross, T. (in press). Reframing sound-shapes in spectromorphological composition: notating perspectival space through spherical, Euclidean and cartesian-coordinate systems, *Organised Sound*.

Cross, T. (in review a). Time series analyses of subjective perceptual responses to variable spectromorphological complexity in electroacoustic stimuli. *Journal of New Music Research.*

Cross, T. (in review b). Analysing the acoustic, perceptual and morphological correlations of spatial, temporal and amplitude complexity in electroacoustic stimuli, *Music and Science*.

Cross, T. (in review c). Morphological fluctuation and listener experience of electroacoustic music: implications for music composition and notation, *Computer Music Journal.*

Cross, T. (2018b). Paradigm Shifts in the Technological Spatialization of Music. In S. Alexandra, Marco Juan de Dios Cuartas (Ed.), *Los nuevos métodos de producción y difusión musical de la era post-digital* (1st ed., pp. 85-98). Ediciones Egregius.

Cross, T. (2019). *Schema: Towards a Post-Biological Composer (2019)*. Spatial Sound Institute, MONOM and CTM 2019. Retrieved December 28 from https://spatialsoundinstitute.com/P_Schema

Cruces-Solís, H., Jing, Z., Babaev, O., Rubin, J., Gür, B., Krueger-Burg, D., Strenzke, N., & Hoz, L. d. (2018). Auditory midbrain coding of statistical learning that results from discontinuous sensory stimulation. *PLoS Biology*, *16*(7), e2005114. https://doi.org/10.1371/journal.pbio.2005114

Danieli, L., Witek, M., & Haworth, C. (2021). Space, sonic trajectories and the perception of cadence in electroacoustic music. *Journal of New Music Research*, *50*(3), 266-278. https://doi.org/10.1080/09298215.2021.1927116

de Berardinis, J., Cangelosi, A., & Coutinho, E. (2022). Measuring the Structural Complexity of Music: From Structural Segmentations to the Automatic Evaluation of Models for Music Generation. *IEEE/ACM transactions on audio, speech, and language processing*, *30*, 1963-1976. https://doi.org/10.1109/TASLP.2022.3178203

Dean, R. T., & Bailes, F. (2011). Time Series Analysis as a Method to Examine Acoustical Influences on Real-time Perception of Music. *Empirical musicology review*, *5*(4), 152-175. https://doi.org/10.18061/1811/48550

Dean, R. T., Bailes, F., & Schubert, E. (2011). Acoustic intensity causes perceived changes in arousal levels in music: an experimental investigation. *PLoS ONE*, *6*(4), e18591-e18591. https://doi.org/10.1371/journal.pone.0018591

Di Stefano, N., Focaroli, V., Giuliani, A., Formica, D., Taffoni, F., & Keller, F. (2017). A new research method to test auditory preferences in young listeners: Results from a consonance versus dissonance perception study. *Psychology of Music*, *45*(5), 699-712. https://doi.org/10.1177/0305735616681205

Duchenne, J.-M. (1991). Habiter l'espace acousmatique. In F. Dhomont (Ed.), *LIEN: L'ESPACE DU SON II* (pp. 82-84).

Eerola, T., Ferrer, R., & Alluri, V. (2012). Timbre and Affect Dimensions: Evidence from Affect and Similarity Ratings and Acoustic Correlates of Isolated Instrument Sounds. *Music perception*, *30*(1), 49-70. https://doi.org/10.1525/mp.2012.30.1.49

Emmerson, S. L. L. (2016). *Expanding the Horizon of Electroacoustic Music Analysis* (S. Emmerson & L. Landy, Eds.). Cambridge University Press. https://doi.org/DOI: 10.1017/CBO9781316339633

Fischman, R. (1997). Analysis of Crosstalk, a work by Michael Vaughan. *Organised sound : an international journal of music technology*, *2*(3), 225-251. https://doi.org/10.1017/S1355771898009078

Geoffroy, V.-R. C. a. J. (2022). On Notational Spaces in Interactive Music. In V. T. a. J. B. a. C. d. P. Santana (Ed.), *Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'2022*.

Gingras, B., Marin, M. M., & Fitch, W. T. (2014). Beyond intensity: Spectral features effectively predict music-induced subjective arousal. *Quarterly journal of experimental psychology (2006)*, *67*(7), 1428-1446. https://doi.org/10.1080/17470218.2013.863954

Gorne, A. v. d. (2015). Space, Sound, and Acousmatic Music: The Heart of the Research ((1. Aufl. ed., Vol. 12, pp. 205-220). transcript Verlag. https://doi.org/10.14361/9783839430767-013

Grewe, O., Nagel, F., Kopiez, R., & Altenmüller, E. (2007). Emotions Over Time: Synchronicity and Development of Subjective, Physiological, and Facial Affective Reactions to Music. *Emotion (Washington, D.C.)*, *7*(4), 774-788. https://doi.org/10.1037/1528-3542.7.4.774

Ham, J. J. (2017). An architectural approach to 3D spatial drum notation. In H. L. P. a. M. S. a. E. T. a. C. Lage (Ed.), *Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'17*. Universidade da Coruna.

Harley, J. (1996). Iannis Xenakis: La Légende d'Eer and Aïs, Gendy3, Taurhiphanie, Thalleïn. *Computer Music Journal*, *20*(2), 124.

Harley, M. (1997). An American in Space: Henry Brant's "Spatial Music". *American Music*, *15*(1), 70-92.

Harrison, J. (2013). What I did on my holidays: The concrete and the ephemeral in acousmatic composition. *Journal of music, technology and education*, *6*(3), 311-322. https://doi.org/10.1386/jmte.6.3.311_1

Haumann, N., Kliuchko, M., Vuust, P., & Brattico, E. (2018). Applying Acoustical and Musicological Analysis to Detect Brain Responses to Realistic Music: A Case Study. *Applied sciences*, *8*(5), 716. https://doi.org/10.3390/app8050716

Henry, M. J., Herrmann, B., & Grahn, J. A. (2017). What can we learn about beat perception by comparing brain signals and stimulus envelopes? *PLoS ONE*, *12*(2), e0172454-e0172454. https://doi.org/10.1371/journal.pone.0172454

Hirst, D. (2011). From Sound Shapes to Space-Form: investigating the relationships between Smalley's writings and works. *Organised sound : an international journal of music technology*, *16*(1), 42-53. https://doi.org/10.1017/S1355771810000427

Holbrook, U. A. S. (2019). Sound Objects and Spatial Morphologies. *Organised sound : an international journal of music technology*, *24*(1), 20-29. https://doi.org/10.1017/S1355771819000037

Honingh, A., Panteli, M., Brockmeier, T., López Mejía, D. I., & Sadakata, M. (2015). Perception of timbre and rhythm similarity in Electronic Dance Music. *Journal of New Music Research*, *44*(4), 373-390.

Huron, D. (2006). *Sweet Anticipation: Music and the Psychology of Expectation*. The MIT Press. https://doi.org/10.7551/mitpress/6575.001.0001

Huron, D. (2019). Musical Aesthetics: Uncertainty and Surprise Enhance Our Enjoyment of Music. *Current Biology*, *29*(23), R1238-R1240. https://doi.org/10.1016/j.cub.2019.10.021

Juslin, P. N., Liljeström, S., Västfjäll, D., Barradas, G., & Silva, A. (2008). An Experience Sampling Study of Emotional Reactions to Music: Listener, Music, and Situation. *Emotion (Washington, D.C.)*, *8*(5), 668-683. https://doi.org/10.1037/a0013505

Juslin, P. N., & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *The Behavioral and brain sciences*, *31*(5), 559-575. https://doi.org/10.1017/S0140525X08005293

Justel, E. (2011). Vers une syntaxe de l'espace. *LIEN: L'ESPACE DU SON III*.

Kamalzadeh, M., Baur, D., & Möller, T. (2016). Listen or interact? A Large-scale survey on music listening and management behaviours. *Journal of New Music Research*, *45*(1), 42-67. https://doi.org/10.1080/09298215.2015.1133655

Kim-Boyle, D. (2014). Visual Design of Real-Time Screen Scores. *Organised sound : an international journal of music technology*, *19*(3), 286-294. https://doi.org/10.1017/S1355771814000272

Kuriki, S., Ohta, K., & Koyama, S. (2007). Persistent Responsiveness of Long-Latency Auditory Cortical Activities in Response to Repeated Stimuli of Musical Timbre and Vowel Sounds. *Cerebral Cortex*, *17*(11), 2725-2732. https://doi.org/10.1093/cercor/bhl182

Landy, L. (2007). *Understanding the art of sound organisation*. MIT Press.

Lippe, C. (1992). Real-time computer music at IRCAM. *Contemporary Music Review*, *6*(1), 219-224.

Lloyd, T., Gaydecki, P., Johannsson, H., Ginsborg, J., & Yates, C. (2018). Listener preference towards a real and emulated violin. *Journal of New Music Research*, *47*(3), 270-274. https://doi.org/10.1080/09298215.2018.1459732

Lotis, T. (2003). The creation and projection of ambiophonic and geometrical sonic spaces with reference to Denis Smalley's Base Metals. *Organised sound : an international* *journal of music technology*, *8*(3), 257-267. https://doi.org/10.1017/S1355771803000232

Lotis, T. (2011). The Perception Of Illusory And Non-identical Spaces In Acouscmatic Music (v.1). *LIEN: L'ESPACE DU SON III*, 63-70.

Lyon, E. (2014, 14 - 20 September 2014). The Future of Spatial Computer Music. (Ed.),^(Eds.). ICMC | SMC | 2014, Athens, Greece.

McAdams, S., Depalle, P., & Clarke, E. (2004). CHAPTER 8 Analyzing Musical Sound (Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195167498.003.0008

McAdams, S., Douglas, C., & Vempala, N. N. (2017). Perception and Modeling of Affective Qualities of Musical Instrument Sounds across Pitch Registers. *Frontiers in Psychology*, *8*, 153-153. https://doi.org/10.3389/fpsyg.2017.00153

Merlier, B. (2018). Space Notation in Electroacoustic Music: From Gestures to Signs. In S. B. a. J. Bresson (Ed.), *Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'18*.

Merlier, B. P., Hélène. (2011). Thélème contemporain et L'ESPACE du son dans la musique électroacoustique la 5ème dimension du son musical. *LIEN: L'ESPACE DU SON III*, 29-38.

Nyström, E. (2011). Textons and the Propagation of Space in Acousmatic Music. *Organised sound : an international journal of music technology*, *16*(1), 14-26. https://doi.org/10.1017/S1355771810000397

Nyström, E. (2017). Morphology of the Amorphous: Spatial texture, motion and words. *Organised sound : an international journal of music technology*, *22*(3), 336-344. https://doi.org/10.1017/S1355771817000498

Otondo, F. (2008). Contemporary trends in the use of space in electroacoustic music. *Organised Sound*, *13*(1), 77-81. https://doi.org/10.1017/S1355771808000095

Patel, A. D. (2010). *Music, Language and the Brain*. Oxford University Press.

Patton, K. (2007). Morphological notation for interactive electroacoustic music. *Organised sound : an international journal of music technology*, *12*(2), 123-128. https://doi.org/10.1017/S1355771807001781

Pearce, M., & Müllensiefen, D. (2017). Compression-based Modelling of Musical Similarity Perception. *Journal of New Music Research*, *46*(2), 135-155. https://doi.org/10.1080/09298215.2017.1305419

Ratti, F. S., & Bravo, C. F. (2017). Space–Emotion in Acousmatic Music. *Organised sound : an international journal of music technology*, *22*(3), 394-405. https://doi.org/10.1017/S1355771817000449

Schlienger, D., & Khashchanskiy, V. (2021). Immersive Spatial Interactivity in Sonic Arts: The Acoustic Localization Positioning System. *Computer Music Journal*, *45*(2), 24-47. https://doi.org/10.1162/comj_a_00605

Schubert, E. (2013). Emotion felt by the listener and expressed by the music: literature review and theoretical perspectives. *Frontiers in Psychology*, *4*, 837-837. https://doi.org/10.3389/fpsyg.2013.00837

Shahin, E. A., Roberts, J. L., Pantev, J. C., Trainor, J. L., & Ross, J. B. (2005). Modulation of P2 auditory-evoked responses by the spectral complexity of musical sounds. *NeuroReport*, *16*(16), 1781-1785. https://doi.org/10.1097/01.wnr.0000185017.29316.63

Smalley, D. (1986). Spectro-morphology and Structuring Processes. In S. Emmerson (Ed.), *The Language Electroacoustic Music* (1st 1986. ed., pp. 61 - 93). Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-18492-7

Smalley, D. (1996). The listening imagination: Listening in the electroacoustic era. *Contemporary Music Review*, *13*(2), 77-107. https://doi.org/10.1080/07494469600640071

Smalley, D. (1997). Spectromorphology: Explaining Sound-Shapes. *Organised sound : an international journal of music technology*, *2*(2), 107-126.

Smalley, D. (2007). Space-form and the acousmatic image. *Organised sound : an international journal of music technology*, *12*(1), 35-58. https://doi.org/10.1017/S1355771807001665

Smalley, D. (2014). *Spatiality in acousmatic music*. Retrieved from https://www.youtube.com/watch?v=_G68Q4gkOMc

Smit, E. A., Milne, A. J., Dean, R. T., & Weidemann, G. (2019). Perception of affect in unfamiliar musical chords. *PLoS ONE*, *14*(6), e0218570-e0218570. https://doi.org/10.1371/journal.pone.0218570

Smit, E. A., Milne, A. J., Dean, R. T., & Weidemann, G. (2022). Making the Unfamiliar Familiar: The Effect of Exposure on Ratings of Unfamiliar Musical Chords. *Musicae scientiae*, *26*(2), 339-363. https://doi.org/10.1177/1029864920948575

Spencer, E. K. (2017). Re-orientating Spectromorphology and Space-form through a Hybrid Acoustemology. *Organised Sound*, *22*(3), 324-335. https://doi.org/10.1017/S1355771817000486

Stenslie, S. (2006). Symbiotic Interactivity in Multisensory Environments. In R. Ascott (Ed.), *Engineering nature : art & consciousness in the post-biological era*. Intellect. Table of contents only http://www.loc.gov/catdir/toc/fy0610/2006278784.html

Contributor biographical information http://www.loc.gov/catdir/enhancements/fy0909/2006278784-b.html

Publisher description http://www.loc.gov/catdir/enhancements/fy0915/2006278784-d.html

Tanzi, D. (2011). Extra-Musical Meanings and Spectromorphology. *Organised sound : an international journal of music technology*, *16*(1), 36-41. https://doi.org/10.1017/S1355771810000415

Tervaniemi, M., Schröger, E., Saher, M., & Näätänen, R. (2000). Effects of spectral complexity and sound duration on automatic complex-sound pitch processing in humans – a mismatch negativity study. *Neuroscience letters*, *290*(1), 66-70. https://doi.org/10.1016/S0304-3940(00)01290-8

Thoresen, L. (2007). Spectromorphological Analysis of Sound Objects: An Adaptation of Pierre Schaeffer's Typomorphology. *Organised Sound*, *12*(2), 129-141.

Tremblay, K. (2007). Training-Related Changes in the Brain: Evidence from Human Auditory-Evoked Potentials. *SEMINARS IN HEARING*, *28*(2).

van Noorden, L., & Moelants, D. (1999). Resonance in the Perception of Musical Pulse. *Journal of New Music Research*, *28*(1), 43-66. https://doi.org/10.1076/jnmr.28.1.43.3122

Wanderley, B. B. a. M. (2015). Tufte Design Concepts in Musical Score Creation. *Proceedings of the First International Conference on Technologies for Music Notation and Representation -- TENOR'15*.

Wanderley, M., Serra, M.-h., Battier, M., Rodet, X., & Pompidou, I. (2001). Gestural Control at IRCAM.

Wang, X. (2013). The harmonic organization of auditory cortex. *Frontiers in systems neuroscience*, *7*, 114. https://doi.org/10.3389/fnsys.2013.00114

Xenakis, I. (1971). *Formalized music : thought and mathematics in composition*. Indiana University Press.

Young, J. (2004). Sound morphology and the articulation of structure in electroacoustic music. *Organised sound : an international journal of music technology*, *9*(1), 7-14. https://doi.org/10.1017/S1355771804000032

Young, J. (2005). Sound In Structure Applying Spectromorphological Concepts. (Ed.),^(Eds.). Electroacoustic music Studies Network, Montreal.

Zoia, E. (2016). Taxonomy and Notation of Spatialization., *Proceedings of the International Conference on Technologies for Music Notation and Representation -- TENOR'16*. Anglia Ruskin University.

Appendices

APPENDIX A. Stimuli for Paper 1

The Stimuli used in Paper 1 can be found in the adjoining files of this thesis entitled "Stimuli for Paper 1".

APPENDIX B. Stimuli for Paper 2

The Stimuli used in Paper 2 can be found in the adjoining files of this thesis entitled "Stimuli for Paper 2".

APPENDIX C. Stimuli for Paper 4

The Stimuli used in Paper 4 can be found in the adjoining files of this thesis entitled "Stimuli for Paper 4".

APPENDIX D. PAPER 5

Cross, T. (2019). Schema: Looking Toward a Post-Biological Composer. *CTM 2019 Persistence*, 20th Edition: Disk Publishing.

Schema: Towards a Post-Biological Composer (2019)

Tiernan Cross

category:
Essay

date:
January 2019

authors:
T ern n Cro

published by:
Spatial Sound
In t tute,
MONOM nd CTM
2019

Tiernan Cross reflects on the impact of increasingly used artificial intelligence, Big Data and Internet meta-organisms as a process of mediation, extension and transformation of human realities and perceptions through the integration of evermore complex intelligent technology. Analysing the impact of learning processes of computing systems which mimic and integrate user-action behavioural tendencies of human responses, as well as exhibiting the footprint of this on the post-biological time and on future paradigms. Hand in hand he exposes the piece Schema, a dialogue between human decision making and automatised computational systems as an exploration of new ways of sound-making, which he has developed during 2018-2019 at SSI for 4DSOUND System and that revolves around his research.

Without doubt, one of the most dynamic factors of change in our modern lives is the ubiquitous presence of digital technology. The increasingly present role of both telematic and self-reliant systems in mixed reality environments are consequently changing the way in which we experience the world around us, and the ways in which the external world perceives us. Respectively, technology offers us information and sensory experiences that would not be possible without the incorporation of computational systems. For the most part, orthodox technology has run parallel with humanity, automated by some form of human interactivity, control or automation( ). We choose which buttons to press on our smartphones, which codes to execute on our computers and which settings to automate our appliances to. As we make these decisions, smart technologies are learning from us, absorbing and decrypting our actions, preferences and choices from a spectrum of possible outcomes before turning these results into organised data. As such, technological intelligence is becoming increasingly attentive and conversant with the various cruxes of human life. The data-sets built upon the choices we make are exceedingly important, bearing economic, political and cultural consequences. Through the continuous act of digitizing our every move, the computing system as an entity has become smart, and through progressions of analytical forecasting, surveillance and calculation it can predict future user actions, intents and behavioural tendencies. In doing so it can also create a mimicry or hyper-mediation of the user, essentially creating a digital copy of the user's mind. But what happens when these smart technologies learn too much? Is there a tipping point where smart technologies and cybernetic systems will have gathered too much information?

Large amounts of this information are gathered through network protocols as platforms such as the Internet facilitate the dissemination of one's self. The Internet as a meta-organism in the current age of Big Data wraps itself around the multifaceted being of humanism, just as much as its impacts, shifts and influences curate proportionate aspects of daily existence. The artificial intelligence and algorithmic capabilities of network protocols have allowed users greater personalised and more individualistic experiences, allowing users to circumnavigate through the excess of the technologically mediated spaces such as the Internet more diligently than ever before. Consequently, network protocols have drastically blurred the boundaries between public and privately information, allowing digital systems to deeply and precisely track the patterns, interrelationships and cycles of human life in a multiplicity of ways. Just as telematic systems have enabled us to source Big Data information from all corners of the globe, they also allow us to intensify and dematerialise our private lives in public spheres, distributing the simulacrum of one's self across telepresent virtual landscapes of a limitless universal and enduring scale(2).

Setting aside the commercial dictation, economic struggles and political warfare that the era of statistical power brings with it, the age of Big Data is one in which we are entrusting our privacy to the machine in hopes to better orchestrate and optimise our lives. As computational systems increasingly infiltrate and occupy our everyday lives, these systems formulate complex libraries of encrypted psychological, sociological, ethical and aesthetic-based information( ). UCSC-based art historian, Edward Shanken, has argued that telematics have the capacity to "expand perception and awareness by merging human and technological forms of intelligence and consciousness through networked communications"(4). In as much, the term 'post-biological' is one used to harness the idea that certain aspects of life are being "mediated, extended or transformed by technology"(5). The implications of such technology can be seen within general cultural evolution, through intelligent technologies exercising reactive and proactive response to situational experiences and through the expansion of human consciousness and the neurological perception of the manifold layers of existence brought about by technologically infused realities. Theorists have continuously questioned the evolution of human consciousness, relaying concepts such as 'moist-media' for the post-biological area, questioning the way in which 'wet', or organic, biological computing (human neurological structures) intergrade with 'dry', or digital computing (technology) and have the capability to enhance and elevate consciousness within the human mind(6). Self-sufficient artificial life is a strong example of a 'dry' post-biological organism at the forefront of modern science as self-aware computers or systems are being built to make execute choice. The intelligent constructs of virtual realities, heterotopic spaces and the Internet are examples of ways in which the human mind integrates post-biological technology or non-material systems. As programming systems more so become the norm, so will the technological systems they code become more intelligent, self-sufficient and self-reliant. Dry computing technologies will become increasingly wet as they adapt and learn to mimic the habitual and instinctual tendencies of the human brain.

As of yet, it is the phenomenon of human emotion that is yet to be replicated. We can never experience the phenomenological world of somebody else, as we cannot directly live it. One can live similar perceptual experiences but never precisely replicate or simulate the exact feeling of somebody else's emotion. Emotion is invaluable in the human brain's decision making process, leaving a trail of debate regarding the plausibility of computer-generated systems truly making decisions based on emotion and not just statistical data that thus falsely try and mimic emotion. Music and art are prime examples of ways in which external sensory stimuli have the capacity to elicit subjective feelings and emotions in the human neurological system. As money is poured into the development of Artificial Intelligence systems with 'human emotions' through data replication in a system's internal logic(7), it forces us to ask the question: will computers reach a point where they can execute truly subjective feeling of their own, or evaluate personal taste of music through experience? Will artificial intelligence finally figure out emotion and integrate such feeling into action?

Over the course of 2017 and 2018, I developed a project to question ways in which post-biological processes could impact computer music composition. The aim of this project was to create an innovative composition surveying how the exponential convergence of telematic network technologies and audio-visual programming languages could shift paradigms of computer based composition further toward the systematics of post-biologics, with further intent to formulate new, hegemonic spatial aesthetics. The creative output of this research is Schema, a 50-minute fixed-media sound composition designed specifically for 4DSOUND. The work thematically frames the nexus of consciousness between human, computer and object in a post-biological world, exploring sonic relationships between self, nature, and technology. In doing so, this research questions the boundaries of our immediate sound realities and how obscure combinations of auditory information and their elaborate spatialisation can develop new modes of listening experiences. In the sense that digital art often draws notions of immateriality while the manifestation of transduced sound itself has a transient lifespan, the resultant composition of Schema blended sound in a concentrated, spatialised setting.

The conceptual foundation of Schema focussed on building an audio programming system that required no human input, no push of a button, performing tasks without human interaction. A self-sufficient archetype of a recording device that required no automation. The device, built as a standalone application, was up and running for roughly 18 months, without human interaction. It would respond to the input and decibel readings of two virtual audio drivers simultaneously, in which the software device would turn itself on and generate systems to capture mixed combinations of sound before auto-assigning these recordings to memory banks and system folders. The resulting composition of Schema is the aggregation of approximately 2800 sound samples using this software device, which effectively captured physical and telematic field recordings through a post-biological approach. Once recorded, the sound data was then intercepted through a series of patches and systematically allocated to allotted spaces on a MacBook Pro's SSDrive, building while the patch reschedules itself to perform repeat processes. The resulting raw samples were then either taken back into the standalone application and arranged systematically via computer algorithms; or imported into the audio editing software Ableton Live and arranged musically via human automation. Thus, creating a schism in the compositional process where biological and post-biological creative decisions are diverging.

Spatially, the composition explored ways in which anomalous combinations of digital sound can enhance auditory perception or intrigue a listener. In both theory and practice, the use of technological sound spatialisation exposes the auditory cortex to heavily controlled experiences of sound across time and space. At the root of the biology to be able to hear and interpret sound, human sensitivity, cognition and perception are required, all of which have co-evolved through constant shifts in the technological fabric of our immediate sound environments(8)(9). Previous research has indicated that exposure to abstract sonic experiences offers potential for the human-neurological system to draw new perceptual dexterity such as improved perception of psychoacoustic processes and increased localisation of sound(10). Consequently, it can be hypothesised that persistent exposure to abstract experiences with sound have the capacity to gradually reorder the inveterate dispositions of 'wet' biological computing, to reorder the way in which our minds localise, analyse and deconstruct augmented combinations of sound in space. In light of this, Schema experiments heavily with ideas of spatial fragmentation, displacement and signal decorrelation, scattering frequential layers of the same, similar or augmented sounds across space through use of the 4DSOUND system.

When hearing Schema in 4DSOUND, it becomes clear that there are listening intricacies formulated through technological construct that would otherwise be unobtainable in physical settings, with augmented combinations of disintegrated sound in space causing listeners to think twice about the clusters of sound objects that surround them. Spatialisation through 4DSOUND allowed sound objects to be disjointed and held in not only time, but also controlled in Cartesian three-space, offering a mode of listening experiences that can essentially only be attained using digital means. The intention of three-dimensional arrangement was to utilise the precision of the system's architecture to present concrete sound information from such post-biological systems in atypical, spatialised formations to stimulate cognitive response to unconventional sound localisation. Examples of this are scattered throughout Schema, in which the same identified sound source can be perceived in more than one location at the same time or seemingly different sources merge together into a perceived hybrid entity.

The final version of Schema was composed and recorded entirely at the Spatial Sound Institute in Budapest in mid 2018 and early 2019, morphing mixed reality soundscapes into spatialized concrete sound collages for 42 discrete loudspeakers. Incorporating post-biological theory, the assembly of Schema is segmented into various sections which all fall upon a spectrum from solely human choice and involvement to solely computer automation; meaning some parts of the composition process were recorded using human performance and response, whilst other parts have solely been left up to algorithmic chance, timing and computer-based decisions. This method was used both in composition and for sound spatialisation to play on the paradigms of human-cyber interaction, which resulted in both the human and the computer taking on separate roles of the composer. Various parts of Schema hold a distinct voice of human imperfection, whilst other sections exhibit qualities of quantised mechanisation as aesthetic choices are formulated by processing algorithms. These are recognisable characteristics, contrasts and frictions that begin to form between human and computer, impacting the listening experience of the composition. As much as it may try to eradicate them, the human mind still holds subconscious cultural bounds of creative aesthetic that are adjusted to modern norms in style, mixing, structure and genre. It is clear through Schema that such bounds occupy a part of the human mind during the artistic process, shaping the composition to what it feels is aesthetically appealing. The computer is free of such parameters, using purely algorithmic choice and probability to shape certain parts of the composition, formulating a different set of sound parameters and creating an entirely different listening experience.

Schema is an example of how the convergence of spatial sound technologies and computer programming languages can shift paradigms in experimental and electronic composition, providing a prognostic outlook toward what could become hegemonic aesthetics in everyday listening experiences. Within Schema, such conditions are tested in an experimental context, but as these conditions become more prevalent in our societies they hold the potential to pervade and effect a much wider range of situations in our daily lives. It can be proposed that further exploration into the use of computer programming languages and high density loudspeaker arrays offers potential to expand our understanding of the complex relationships between human, sound and space. Whilst mixed realities and the free-flow of audio-visual hyperdata distributed across post-biological systems are consequently reconfiguring our perceptual experiences of the world(11), complex auditory systems such as 4DSOUND allow these perceptual experiences to be tested even further. It becomes clear that the post-biological and technological infrastructures of the 21st century are revolutionising the landscape and deliverance of sound in ways that could not have been previously anticipated. As a result of these infrastructures and their resulting paradigms in sensory data, our relationship with sound is being rearranged entirely whilst technology as an artistic tool offers immense systematic growth in supporting human expression in creativity. Considering the rapid rate of computer-based progression and the potential free agency of artificial intelligence, it becomes important to think about the future of the human mind and its role in creativity, to question ways in which human consciousness could become redundant to artificial systems.

The future of post-biological systems in music is almost guaranteed. Schema as a whole is nothing more than a combination of frequency outputs formulated through a series of both human and computer decision-making. Whilst computing systems have yet to master human emotion, the boundaries of sound composition are practically non-existent. It could become increasingly difficult for a listener to determine what was creatively human driven and what is purely algorithmic. Whilst artificial systems have not grasped emotive response and its application in music, they are able to mimic human action, indicating a probability that they will be able to learn so much that their actions might give the facade of emotive response.

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About the Author

Tiernan Cross is a composer, sound artist and researcher based in Sydney, Australia. As the current recipient of the University of Sydney's

Eleanor Dunne Scholarship, Tiernan is completing postgraduate research through the Sydney Conservatorium of Music, focusing on neurological conditioning, composition and post-biological sound aesthetics.

His research and compositional practice questions the relationships between the evolution of perceptual encounters and ways in which we as humans neurologically process complex combinations of sound in mixed-reality environments. Classically trained through the Sydney Conservatorium of Music, Australian Film, Television & Radio School's postgraduate program and the Sydney School of Architecture, Tiernan's works have been exhibited and performed in China, France, Belgium, Spain, Canada, USA, Australia, Germany and Japan. Tiernan also holds a Bachelor's Degree in Communication from Griffith University.

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References

1. Rossow, A. (2018). Artificial Intelligence and Smart Technology Is Bringing Convenience To A Whole New Level. Retrieved from https://www.forbes.com
2. Ascott, R. (2006). Introduction. In R. Ascott (Ed.), Engineering nature : art & consciousness in the post-biological era. Bristol, UK: Intellect, pp. 9-10.
3. Berry, D. M., & Dieter, M. (2015). Postdigital aesthetics: art, computation and design. Basingstoke: Palgrave Macmillan.
4. Ascott, R. and Shanken, E. A. (2003). Telematic Embrace: Visionary Theories of Art, Technology and Consciousness, Berkeley, CA: University of California Press, pp. 6.
5. Ascott, R. (1998). Consciousness Reframed: Art and consciousness in the post-biological era. Digital Creativity, 9(1), pp. 5-6.
6. Ascott, R. and Shanken, E. A. (2003). Telematic Embrace: Visionary Theories of Art, Technology and Consciousness, Berkeley, CA: University of California Press, pp. 1.
7. Darlington, K. (2018). AI Systems Dealing with Human Emotions. Retrieved from https://www.bbvaopenmind.com/en/ai-systems-dealing-with-human-emotions/.
8. Borgo, D. (2013). 'Beyond performance transmusicking in cyberspace', in N. Cook and R. Pettengill (eds), Taking It to the Bridge, Ann Arbor, MI: University of Michigan Press, pp. 319–348.
9. Sterne, J. (2003), The Audible Past: Cultural Origins of Sound Reproduction, Durham, NC: Duke University Press.
10. Cross, T. (2018). Neurological perception and sound-based creativity in post-biological realities: Recontextualizing reflective practice for technoetic environments. Technoetic Arts: A Journal of Speculative Research, 16(1), Bristol, UK: Intellect, pp. 23-31.
11. Stenslie, S. (2006). 'Symbiotic interactivity in multisensory environments', in R. Ascott (ed.), Engineering Nature: Art and Consciousness in the Post-Biological Era, Bristol, UK: Intellect, pp. 153–158.

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Related:

‘Schema’ (2018-2019)
[PROJECT]

Psychoacoustics: An Introduction (2014)
[PUBLICATION]

APPENDIX E. COMPOSITION (00:48:26)

Cross, T. composer. "*Schema*". MONOM, Berlin Germany, 2019.

This additional composition portfolio can be found in the adjoining files of this thesis entitled "Schema (00:48:26). Though dispersed across a 48.9 speaker system, the adjoined rendering of the composition has been formatted for stereophonic playback.

APPENDIX F.1. Ethics Approval

Research Integrity & Ethics Administration
HUMAN RESEARCH ETHICS COMMITTEE

Monday, 16 August 2021

Assoc Prof Helen Mitchell
Musicology Unit; Sydney Conservatorium of Music
Email: helen.mitchell@sydney.edu.au

Dear Helen,

The University of Sydney Human Research Ethics Committee (HREC) has considered your application.

I am pleased to inform you that after consideration of your response, your project has been approved.

Details of the approval are as follows:

Project No.:	**2021/322**
Project Title:	**Listener Responses to Computer-Enhanced Auditory Stimuli**
Authorised Personnel:	**Mitchell Helen; Cross Tiernan;**
Approval Period:	**16/08/2021** to **16/08/2025**
First Annual Report Due:	**16/08/2022**

Documents Approved:

Date Uploaded	Version Number	Document Name
26/07/2021	Version 2	Revised-Participant_Information_Statement
10/05/2021	Version 1	REDCap Consent Questions
03/05/2021	Version 1	Participation Call Out

Condition/s of Approval

- Research must be conducted according to the approved proposal.
- An annual progress report must be submitted to the Ethics Office on or before the anniversary of approval and on completion of the project.
- You must report as soon as practicable anything that might warrant review of ethical approval of the project including:
  - Serious or unexpected adverse events (which should be reported within 72 hours).
  - Unforeseen events that might affect continued ethical acceptability of the project.
- Any changes to the proposal must be approved prior to their implementation (except where an amendment is undertaken to eliminate *immediate* risk to participants).
- Personnel working on this project must be sufficiently qualified by education, training and experience for their role, or adequately supervised. Changes to personnel must be reported and approved.
- Personnel must disclose any actual or potential conflicts of interest, including any financial or other interest or affiliation, as relevant to this project.

- Data and primary materials must be retained and stored in accordance with the relevant legislation and University guidelines.

- Ethics approval is dependent upon ongoing compliance of the research with the *National Statement on Ethical Conduct in Human Research*, the *Australian Code for the Responsible Conduct of Research*, applicable legal requirements, and with University policies, procedures and governance requirements.

- The Ethics Office may conduct audits on approved projects.

- The Chief Investigator has ultimate responsibility for the conduct of the research and is responsible for ensuring all others involved will conduct the research in accordance with the above.

This letter constitutes ethical approval only.

Please contact the Ethics Office should you require further information or clarification.

Sincerely,

[REDACTION]

Dr Jennifer Rowley
Deputy Chair
Conservatorium Review Committee (Low Risk)

The University of Sydney of Sydney HRECs are constituted and operate in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Human Research (2018) and the NHMRC's Australian Code for the Responsible Conduct of Research (2018)

APPENDIX F.2. Participation Information Statement

THE UNIVERSITY OF SYDNEY

Discipline of Musicology
Sydney Conservatorium of Music

ABN 15 211 513 464

Dr Helen Mitchell
Associate Professor

Room 2081
Conservatorium of Music C41
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DECIPHERING NEW SOUNDS: ANALYSING RESPONSE TO COMPUTER-ENHANCED AUDITORY STIMULI

STUDY 1

PARTICIPANT INFORMATION STATEMENT

(1) What is this study about?

You are invited to take part in a research study investigating how technologies are changing the ways in which the human brain comprehends complex computer-generated sounds. As studies begin to show that technology is changing our brain responses to new information and stimuli, it becomes increasingly important to question ways in which combinations of natural and synthesized sounds brought about by computing technologies could be evoking change in human neuroplasticity. By inviting participants to undergo a series of listening tests, this study aims to monitor participants listening to a variety of sounds and musical cues ranging from spatiotemporally 'dull' to 'complex' in an attempt to better understand listener preference to intricate computer-generated motifs in music composition.

This Participant Information Statement tells you about the research study. Knowing what is involved will help you decide if you want to take part in the research. Please read this sheet carefully and ask questions about anything that you don't understand or want to know more about.

Participation in this research study is voluntary.

By giving your consent to take part in this study you are telling us that you:

- ✓ Understand what you have read.
- ✓ Agree to take part in the research study as outlined below.
- ✓ Agree to the use of your personal information as described.

You will be given a copy of this Participant Information Statement to keep.

(2) Who is running the study?

The study is being carried out by the following researchers:

- Tiernan Cross, PhD Candidate, The University of Sydney

Tiernan Cross is conducting this study as the basis for the degree of Doctor of Philosophy at The University of Sydney. This will take place under the supervision of Dr Helen Mitchell, Associate Professor.

(3) What will the study involve for me?

To be eligible for this study you need to pass the following screening questions:

You have no known cognitive impairments, problems hearing or health issues that directly impact your cognition of audio-visual stimuli. *This is required as part of the screening process as individuals with any of the above conditions may skew the data analysing process.*

You are able to communicate fluently using the English language. *This is required as the listening sessions will be conducted in English and you must be able to give your fully formed consent and understanding of the processes that take place within your listening session. There will be no interpreter involved / present during these listening sessions.*

There are no geographical restrictions in place for these listening sessions as they will be conducted virtually. *The need for retesting is very unlikely.*

The main aim of these listening sessions is to see how participants respond to combinations of 'dull and 'complex' computer-generated sounds in succession to one another.

The study will involve you, as the participant, sitting in a comfortable place (preferably a quiet space in your home) for roughly 15 minutes, listening to a series of sounds through a set of speakers. Each sound will be roughly 2 seconds in length, with a total of 180 sounds in total. You will be required to attend one listening session in total. Due to COVID-19, these sessions will take place virtually, with participants digitally sent all relevant materials (audio files, instructions and Google Docs files. These sessions are proposed to take place during August – September 2021. Frequent breaks are interspersed in the recording task (one break every 3 minutes).

Prior to the listening session, some broad personal information will be requested from you in the form of a questionnaire to better categorize trends that may appear in the data and to better understand the overall inclusion of the population of interest. These questions will include your age group, musical ability and dexterity (left or right-handed). Contact information will also be requested, solely for the researcher of CI to provide further information on the study if you request it. If you have granted preapproval on the screening questionnaire, researcher or CI may use this information to contact you during the study to see if you would be willing to participate in further studies during the researcher's doctoral candidature. If you have not given approval, your contact information will not be used for this purpose. No further personal information will be requested and at no time will any of your personal information be given to any internal or external third parties.

Your details and data will be kept anonymous and no identifiable personal information will be used or published with this research. As data gathered will be non-identifiable, there will be no opportunity to review the information generated before publication.

(4) How much of my time will the study take?

The testing will take roughly 20 minutes in total. You will be asked to listen to a series of 180 two-second musical cues, with the listening session itself only lasting roughly 15 minutes, including. An additional five minutes should be allowed for reading documentation / instructions for the prepared listening task. Frequent breaks will take place during the session (one thirty second break every three minutes). After the listening session, you will be invited to fill out a second two-minute questionnaire, answering multiple choice questions that best detail your experience. This is the total time commitment required from you.

(5) Who can take part in the study?

We are looking for individuals between the ages of 20-45 with a keen interest in a mix of modern popular music, electronic music, computer music and traditional orchestral music. Individuals with and without experience in music theory are both encouraged to apply. Apart from the screening and exclusion criteria listed above (Section 3), there are no other prerequisites to take place in this study.

(6) Do I have to be in the study? Can I withdraw from the study once I've started?

Being in this study is completely voluntary and you do not have to take part. Your decision whether to participate will not affect your current or future relationship with the researchers or anyone else at the University of Sydney.

If you decide to take part in the study and then change your mind later, you are free to withdraw at any time. You can do this by emailing Tiernan Cross via email (tcro7275@uni.sydney.edu.au) with intent to withdraw from this study at which point no further data will be collected from you. If you have already completed a listening session, you can have your data destroyed, but you need to clearly as soon as possible as to not disrupt the overall process of this study. Please let us know at the time when you withdraw what you would like us to do with the information, we have collected about you up to that point. If you wish your information will be removed from our study records and will not be included in the study results, up to the point that we have analysed and published the results. Once this study has been compiled and published you will not be able to withdraw any data that has been collected.

Submitting your completed questionnaire is an indication of your consent to participate in the study. You can withdraw your responses if you change your mind about having them included in the study, up to the point that we have analysed and published the results.

(7) Are there any risks or costs associated with being in the study?

Aside from giving up your time, we do not expect that there will be any risks or costs associated with taking part in this study.

(8) Are there any benefits associated with being in the study?

We cannot guarantee that you will receive any direct benefits from being in the study.

(9) What will happen to information about me that is collected during the study?

By providing your consent, you are agreeing to us collecting personal information about you for the purposes of this research study. Your information will only be used for the purposes outlined in this Participant Information Statement, unless you consent otherwise.

Your information will be stored securely, and your identity/information will be kept strictly confidential, except as required by law. Study findings may be published, but you will not be individually identifiable in these publications.

All personal information collected from participants (age, musical ability etc) will remain anonymous throughout the course of this research and any future research conducted. Any information gathered will only be published as part of an amalgamation of the overall trends found in the data across all recipients as a whole (e.g. '*participants aged 21-30 responded differently to participants aged 31-40).*

No third parties will have access to any participant information or data during or after the study. Your personal information will be kept confidential during and after this study. Individual data collected during this study will not be shared, nor will it become restricted, mediated or open access.

These results will be published in the form of a student theses and potential future conference presentations, journal publications and academic essays. A copy of the personal information gathered in this study will be unavailable to participants.

Electronic copies of participant data will be encrypted and stored on the University supported Research Data Store (RDS) system and on an encrypted hard-drive stored in a secure office at the Sydney Conservatorium of Music whilst hardcopies will be kept in a secure office at The Sydney Conservatorium of Music, before ultimately being converted into electronic copies. Once hardcopies have been converted, the physical originals will be destroyed. At the conclusion of this study, electronic copies will remain encrypted and be archived electronically on the Research Data Store for a total of five (5) years. The data collected may be used in future research projects undertaken by the researcher Tiernan Cross, with all participant information remaining non-identifiable throughout any future project commencement.

We will keep the information we collect for this study, and we may use it in future projects. By providing your consent you are allowing us to use your information in future projects. We don't know at this stage what these other projects will involve. We will seek ethical approval before using the information in these future projects.

(10) Can I tell other people about the study?

Yes, you are welcome to tell other people about the study.

(11) What if I would like further information about the study?

When you have read this information, Tiernan Cross will be available to discuss it with you further and answer any questions you may have. If you would like to know more at any stage during the study, please feel free to contact Tiernan Cross (researcher) at tcro7275@uni.sydney.edu.au or +61 [REDACTION] [redacted].

(12) Will I be told the results of the study?

You have a right to receive feedback about the overall results of this study. You can tell us that you wish to receive feedback by *ticking the relevant box on the consent form.* This feedback will be in the form of *a one page lay summary.* If requested, you will receive this feedback after the study is finished.

(13) What if I have a complaint or any concerns about the study?

Research involving humans in Australia is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this study have been approved by the HREC of the University of Sydney *[2021/322* protocol number, approval obtained*].* As part of this process, we have agreed to carry out the study according to the *National Statement on Ethical Conduct in Human Research (2007).* This statement has been developed to protect people who agree to take part in research studies.

If you are concerned about the way this study is being conducted or you wish to make a complaint to someone independent from the study, please contact the university using the details outlined below. Please quote the study title and protocol number.

The Manager, Ethics Administration, University of Sydney:

- **Telephone:** +61 2 8627 8176
- **Email:** human.ethics@sydney.edu.au
- **Fax:** +61 2 8627 8177 (Facsimile)

This information sheet is for you to keep

APPENDIX F.3. Participant Consent Form

Participant Consent Form

Participant group 1

Research Study:

DECIPHERING NEW SOUNDS:
ANALYSING RESPONSE TO COMPUTER-ENHANCED AUDITORY STIMULI

Dr Helen Mitchell (Responsible Researcher)
Sydney Conservatorium of Music
Phone: +61 2 9351 1250 | Email: helen.mitchell@sydney.edu.au
Mr Tiernan Cross (Doctor of Philosophy student) | Email: tcro7275@uni.sydney.edu.au

Participant Name ____

I agree to take part in this research study. In giving my consent, I confirm that that:

- The details of my involvement have been explained to me, and I have been provided with a written Participant Information Statement to keep.
- I understand the purpose of the study is to investigate how participants respond to combinations of 'dull and 'complex' computer-generated sounds in succession to one another.
- I acknowledge that the risks and benefits of participating in this study have been explained to me to my satisfaction.
- I understand that in this study I will be required to sit through a listening test for roughly 15 minutes, filling in a questionnaire as I listen to a series of auditory and musical cues through a set of headphones. Each sound will be roughly 2 seconds in length, with a total of 180 sounds in total. I will be required to attend one listening session in total. Due to COVID-19, I understand that these sessions will take place virtually and that I will be sent all relevant materials (audio files and questionnaires) and ample instructions on how to complete the listening test independently. I understand that sessions are proposed to take place during July – August 2021.
- I understand that my information may be used in future research, though it will be anonymised so that no data can be linked to my person. I understand that any raw data collected will not be shared or viewed by anybody other than the Chief Investigator and Mr Tiernan Cross.
- I understand that being in this study is completely voluntary.
- I am assured that my decision to participate will not have any impact on my relationship with the research team or the University of Sydney.

- I understand that I am free to withdraw from this study at any time and that I can choose to withdraw any information I have already provided (unless the data has already been de-identified or published).

- I have been informed that the confidentiality of the information I provide will be protected and will only be used for purposes that I have agreed to. I understand that information about me will only be told to others with my permission, except as required by law.

- I agree that I will not distribute any of the files used in this study, and that all music and sounds used in this study are the creation and intellectual property of the co-investigator Tiernan Cross.

- I understand that the results of this study may be published, and that publications will not contain my name or any identifiable information about me.

- I confirm the following:

I consent to being contacted for future studies	Yes ☐	No ☐
I consent to my data being used in future research	Yes ☐	No ☐
I would like feedback on the overall results of this study	Yes ☐	No ☐

If you answered **yes**, please provide your preferred contact details (email/telephone/postal address):

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- I understand that after I sign and return this consent form it will be retained by the researcher, and that I may request a copy at any time.

Participant Name ______________________________

Signature ______________________________

Date ______________________________