Towards a Perceptually–grounded Theory of Microtonality: issues in sonority, scale construction and auditory perception and cognition

Brian Bridges

Thesis submitted to the National University of Ireland, Maynooth, for the degree of Doctor of Philosophy

Volume 1 of 2

Department of Music

National University of Ireland, Maynooth

October 2012

Head of Department: Prof. Fiona M. Palmer

Supervisor: Dr Victor Lazzarini

Table of Contents

List of Figures

Acknowledgements

Firstly, I wish to express my debt to my supervisor, Dr Victor Lazzarini, who has not only supervised the present project, but has also been a formative influence since I first encountered him whilst I was an undergraduate student at Maynooth. One of the earliest questions which informed this project relates to the factors which affect the perception of individual notes in a tone–cluster, something which I began to haltingly frame questions about as a result of some very early studies for Victor's undergraduate module in electroacoustic composition.

The present study also arises out of an interest in microtonal tunings in New York experimental music which I first engaged with during my MPhil in Music and Media Technologies at TCD. I would like to thank those who mentored me on my compositions and dissertation, including Dr Dermot Furlong, who opened my mind to the world of perceptual factors at play in music, and composition tutors Donnacha Dennehy and Jürgen Simpson, who helped frame my early interest in this area. In this type of perceptually–grounded microtonalism, the name of Glenn Branca looms large. Although his music is not treated in detail in the present work (it would take another doctorate to properly cover it), some of the musical questions which he poses are, I hope, addressed. I thank Glenn for his support of my quest for answers and promise to be a better correspondent now that this project is over (and so many questions still remain)!

During the course of the project, I moved from Dublin to Derry, leaving me with a case of cultural double–vision whose fruits are perhaps becoming apparent as the dust settles. I owe a particular debt of gratitude to Michelle for making the same move a couple of years after I did to share this 'PhD space' with me both metaphorically and, as it began to take over large parts of the flat, quite literally. Without her love and patience, not to mention sanity, the process would have been even more tortuous than it seems a PhD sometimes just has to be! Words can’t properly express my gratitude right now, so let’s talk about it on holiday… My family has been a constant source of support and advice over the years. My father and mother (Derek and Ann) and brother (Michael) have always been there to talk sense and provide inspiration and encouragement. Thanks also to family friend Pete Hamilton, who lent me my first synthesisers and introduced me to a world of music beyond the mid–eighties mainstream of my youth. More recently, thanks also to Michelle's family, for their welcomes and for their conversational dexterity, which has occasionally reminded me how to be sociable again.

As I write this, I'm conscious of how little I've seen my friends over the last four years. So, thanks to all of you for being there over the years, even if I haven’t seen much of you recently: Rob Naik, Hugh, Owen, Lisa, Mick, Legs, Lib, Julie, Bryan, Frank, Christophe, Tara, Nathan, Mark L. Thanks to Dr Paul Moore (University of Sydney) for being a new old friend who was one of the few visitors to see the inside of ‘PhD space’ and who helped to define it. Thanks to Mark F, for his advice and adherence to the principle that it's sometimes good to have music out there that people don't like (yet). To Rich, for 'the Brain' and much analogue talk. To Phil for lots of digital talk and more music.

I would like to acknowledge the support of Professors Gillen and Palmer for their mentoring throughout this PhD and would like to express my gratitude for the time I have spent at the Maynooth Music Department. I would like to thank NUIM for the support of the John and Pat Hume Scholarship, which prefigured my present connection with Derry. I would like to thank my colleagues and students at the School of Creative Arts, University of Ulster, Derry, for welcoming me during hectic times as we established the new creative technologies (CT) degree and developed new music technology ideas for the music degrees. In this regard, thanks to my CT colleagues Prof. Paul Moore and Greg O'Hanlon for working closely with me during this formative period. But I should also give particular thanks to all of those colleagues who took the time to remind me that there was 'one other thing' which I needed to return to! (Almost all of you have been kind enough to do this, so I won't single anyone out!) It's also been a pleasure to work with three talented PhD students whilst at Ulster: Dr Ricky Graham, John King and Brendan McCloskey. Thanks to my co–supervisor, Prof. Frank Lyons for bringing me in on these projects; even if it did make my own thesis a little slower in coming, it has been a rewarding and valuable experience!

Many talented musicians and fellow–composers helped me realise performances and exhibitions of some of the pieces contained herein. A big thanks to all of my colleagues in the Spatial Music Collective for musical inspiration and friendship, particularly to Linda, who I first met on a dark and stormy night when she was creating her requiem, to Enda for his drive in developing the SpatialMC over the last few years and to Jonathan for his infectious musical enthusiasm. Thanks to Marc Balbirnie, who conducted *Angels at the Shotgun Wedding*, to the musicians of the Maynooth Electric Guitar Array (over twenty BA Music Technology, BMus and MA Computer Music students from Maynooth in 2007/08). To Dr Benoit Granier, for his musical example, deadpan humour (or, occasionally, deadpan slagging, being Beijing's leading honorary Irish Frenchman) and for his invitations to China to work with the TiMi Ensemble; thanks also to the talented musicians of TiMi in 2010 and 2012. Many thanks to Paul Harrigan for good humour and great musicianship on that first mad expedition to Beijing. To Ben Schlepper–Connolly, Francis Heery and Garret Sholdice for their performance on Infraction (and to Ben and Garret for their successful Ergodos Off–Grid Festival in 2009). Thanks to the musicians of the Bridgewood Ensemble (2008) for the premiere of *Flatlining.* A general thanks to all others who have helped me, but aren't mentioned here. I could blame my Dublin–Derry dislocation for it slipping my mind, but it's probably better if I just make it up to you in person!

Abstract

This thesis engages with the topic of microtonal music through a discussion of relevant music theories and compositional practice alongside the investigation of theoretical perspectives drawn from psychology. Its aim is to advance a theory of microtonal music which is informed by current models of auditory perception and music cognition. In doing so, it treats a range of microtonal approaches and philosophies ranging from duplex subdivision of tempered scales to the generation of intervals in just–intonation–based schemes, including systems derived directly from the structure of the harmonic series. It contains an analytical survey of case studies relating to twentieth–century microtonal approaches, focussing on the conceptual and perceptual implications of the use of such materials by these early microtonal practitioners, through engagement with their stated theories and compositional practice. Through this process, it begins to advance components of a perceptually and cognitively–informed theory of microtonality, which is then consolidated by a series of theory–based chapters which investigate the phenomenon from the perspective of current theories within the field of psychology. The theories which are thus advanced are further informed by a component of compositional practice in the research process, which is used as a vehicle to refine and extend them. The result is a comprehensive theory of microtonal music which incorporates contexts drawn from ecological and embodied perspectives on perceptual and cognitive processes.

Relevant Concert Presentations by the Author

The following performances relate to the pieces enclosed in the composition portfolio section of this thesis submission. Further details can be found at www.brianbridges.net

Angels at the Shotgun Wedding (23 electric guitars and tape), performed by the Maynooth Electric Guitar Array, **Soundings 0402**, Daghdha Space, Limerick, 2nd April 2008 and The Venue, NUI Maynooth, 8th April 2008

Flatlining (string quartet), **The Spatial Music Collective Presents the Bridgewood Ensemble**, SS Michael and John (Smock Alley Theatre), Temple Bar, Dublin, 26th June 2008

Infraction (e-bow electric guitar, violin, viola), performed by Garret Sholdice: e-bow guitar; Benedict Schlepper-Connolly: violin; Francis Heery: viola, **Expressway to Yr Skull, Ergodos Off-Grid Festival**, Unitarian Church, St. Stephen's Green, Dublin, 23rd April 2009

Making Ghosts from Empty Landscapes (pipa, erhu, uillean pipes, 2 violins and tape), performed by the TiMi Modern Music Ensemble with uillean piper Paul Harrigan, **Beijing Irish Contemporary Music Festival 2010**, La Plantation, Beijing, 28th March 2010

A Space for Tension (erhu, 2 violins and tape), performed by the TiMi Modern Music Ensemble, **Beijing Irish Contemporary Music Festival 2012**, Central Conservatory of Music Concert Hall, Beijing, 18th March 2012

Chapter 1: Introduction, Aims and Structure, Definitions and a Historical Survey of Tuning and Scale Construction in Western Music

1.1 Introduction

The present thesis provides an account of key issues in the practice of contemporary microtonal composition with a particular focus upon those which relate to my own compositional practice. The investigations which are discussed in this thesis are based on two initial components: (1) research into the practices of earlier microtonal composers and the development of a theoretical framework relating to their practice; and (2) the creation of a portfolio of microtonal compositions. These components of the research process will lead to the development of a theory of microtonal composition which is based upon a synthesis of current thinking in the fields of auditory perception and music cognition and analyses of examples of various microtonal practices within the field of contemporary composition. In particular, this research project has as one of its goals the exploration of *just–intonation*–based microtonality (i.e. based on tunings which use integer frequency ratios) and its implications in terms of auditory grouping/segregation and the perception of musical structures. This aspect of musical structuring is investigated with reference to its implications regarding the relationship between key concepts such as the perception and categorisation of musical intervals, consonance/dissonance, harmony and timbre.

Microtonal music, with its potential for increased complexity through the subdivision of standard intervals, could leave itself open to a charge of providing overly complex formal structuring opportunities which may be redundant in relation to the listener's cognitive–perceptual abilities. It may be argued that the primary function of such an overabundance of formal structuring opportunities may be to provide a satisfying compositional superstructure for the practitioner to use as a framework or inspiration by which to organise aspects of the music which have the potential to *actually be heard* (in the sense of perceiving structure). However, it is a working assumption of the present project that if not directly accessible to a listener in perception (and resultant cognition), such structures can be regarded as extramusical (and are of little relevance in this project's search for musical materials which comprise 'perceptually valid' microtonal materials).

1.2 Outline of Aims and Thesis Structure

This thesis aims to develop a comprehensive theory of microtonal music which can be applied to a range of practices throughout this broad field, but with particular applicability to microtonality which is related to just intonation approaches. The intention is that the theoretical perspectives presented will be informed by current models of auditory perception and music cognition, such that its explanations of the behaviour of microtonal materials will be consistent with these models. The extant theories of psychology relating to auditory experience are primarily concerned with producing generalised frameworks which account for more typical or commonplace structures in the environment or in music. These perspectives therefore tend towards normative descriptions of the types of structures which may be clearly perceived and apprehended.[1] Given the research priorities and processes within that field, this imperative is understandable, but from the compositional perspective it leads to a neglect of more exploratory creative practice which engages with less straightforward structural approaches. In this regard, much of the existing commentary on psychologically–informed approaches to musical structuring tends to decry microtonal practice as a willful disregard of the limits of human perceptual processing capabilities. However, the present work will seek to present a defence of microtonality through explanations of potential processes for its reception which are broadly consistent with models and findings within the psychology field, but which also take into account the more particular perceptual circumstances (and, hence, potential inter–relations between perceptual processes) which the use of microtonal materials may entail. It will therefore endeavour to find agreement between the experiences and theories of practitioners of microtonal music and the potentially grounding influence of psychological theories.

The thesis will thus investigate microtonal music from a number of different perspectives. This introductory chapter will provide preliminary definitions, summaries and contextualisation for the theoretical perspectives which will be employed throughout, alongside a historical introduction to the history of scale construction and interval definition in Western music. Chapter two will provide an analytical survey of early microtonal composition in the twentieth century based on the subdivision of the standard twelve–division equally–tempered scale. In addition, it will also discuss so–called *hybrid approaches* which seek to integrate this *subdivision impulse* with the

[1] This may be due either to the focus on relatively simple stimuli in more decontextualised contexts on the one hand, or, where more musically contextualised research is conducted, it may prioritise the study of musical structures derived from Western music's common practice.

competing concern for close approximations of integer–based interval definition (*just intonation*). Chapter three will investigate the theoretical perspectives and related compositional practice of the early just intonation pioneers Harry Partch and Ben Johnston, with a particular focus on their models of relationships between microtonal materials. Chapter four will discuss the work of two just intonation composers of a later generation, La Monte Young and James Tenney, with a treatment of their work as it relates to environment–influenced models of musical composition and their relationships to perceptual processes. Following these analyses of historical microtonal practice and compositional theories, the next two chapters will advance a framework which is more comprehensively based on current psychological theories relating to sensory perception and higher–level cognitive processing of these percepts. Chapter five is entitled 'The Psychology of Intervals' and will discuss categorisation processes and cognitive limits which may have an impact on the reception of microtonal materials. Chapter six—'The Psychology of Pitch–Spaces'—will investigate cognitive structures which describe relationships between intervals, with a particular focus on *ecological* and *embodied* models of cognition (see introduction to these terms in section 1.3.4, below). The intention of this division of materials is that microtonality be addressed in a comprehensive fashion based on an awareness of the impact of various levels and aspects of our processing of perceptual information. Chapter seven discusses the portfolio of microtonal compositions which was completed as part of the research towards this thesis. This provides a practice–led perspective which is intended to contribute to a refinement of the models of microtonality discussed in earlier chapters. The concluding chapter will integrate theoretical perspectives from throughout the thesis with the practice–informed insights.

1.3 Preliminary Definitions

A number of key terms and concepts will be defined in this section so as to provide anintroductory context which will inform the initial chapters. Definitions will be restated on first usage in the succeeding chapters of this thesis, with short definitions for the most important terms also being available in appendix one to facilitate cross–referencing at other points.

1.3.1 Defining and Delineating Microtonality and Related Terms

For the sake of clarity, a preliminary definition of microtonal music will be presented here: music which utilises divisions of the octave which are smaller than the smallest structural divisions of the tone in common musical practice in Western music (and, indeed, in many world musics). As such, it is music which utilises divisions smaller than the standard semitone of twelve–tone equal temperament or closely related systems of tempered or non-tempered tuning (Johnston 1971, p.41). Examples include those scales which are based on the duplex subdivision of the standard semitone into smaller intervals, creating from *12TET* (twelve–tone equal temperament)[2] systems of *24TET*, *36TET, 72TET* etc. This approach was particularly favoured by early microtonal pioneers such as Julián Carrillo (1875–1965) and Alois Hába (1893–1973), in addition to usage by composers such as Ligeti who make more occasional use of microtonal materials based on quartertones (24TET).

Another strand of microtonalism is derived from a different impulse—the preference for

---

[2] An alternative nomenclature, 12EDO, or twelve equal divisions of the octave, is sometimes preferred in discussions of scale structure, to distinguish from the equal division of non-octave-based scales. This thesis will generally prefer the *TET* over *EDO*, due to its more widespread usage and will be used to refer to octave-based scales in all such cases.

mathematically ‘pure’ tunings in *just intonation* schemes—which can be summarised as a concern for the tuning of intervals with relatively simple integer-based frequency ratios, facilitating a greater degree of consonance in the context of periodicity/minimising beats (hence, the ‘purity’ noted above). Advocates of this approach—including Harry Partch (1901–1974) and La Monte Young (born 1935)—frequently begin by reverting to tuning practices derived from historical music practices, such as documented practice from ancient China, Classical Greece and Western music from before the Baroque era, when a Pythagorean–style equation of numerical simplicity with consonance was assumed. Their investigations of just intonation/‘pure tuning’ versions of common intervals can lead to the creation of a variety of distinct tunings for a given interval. Such examples include the enharmonic and tuning distinction between *C#* and *Db* implied by strict adherence to just intonation processes of interval generation (only preserved in functional distinctions in 12TET practice). However, they also include a variety of different approaches to the rendering of established diatonic and chromatic intervals using different integer frequency ratios; see Gann (1998) for a comprehensive list of just intonation variations of familiar interval types.

It should be stressed that the use of a single just intonation variant of a particular interval in the context of scale constructions with a small number of steps (e.g. 5, 7, 12) does not *in itself* satisfy the definition of microtonality as stated above. A pentatonic or heptatonic scale which makes tuning choices which are different from the standard Western 12TET tuning (for example, from non-Western or historical practice) is better described as being based upon *alternate/alternative tuning*.[3] More generally, *xenharmonic* practice (Darreg, 1966) describes alternative scale structures and harmonic practices. Its initial coinage implied that it was focussed on microtonal practice but was later elaborated so that it acted as a supra-category encompassing *both* microtonality and alternative tuning for scales with small numbers of steps (Darreg, 1974); see figure 1, below.

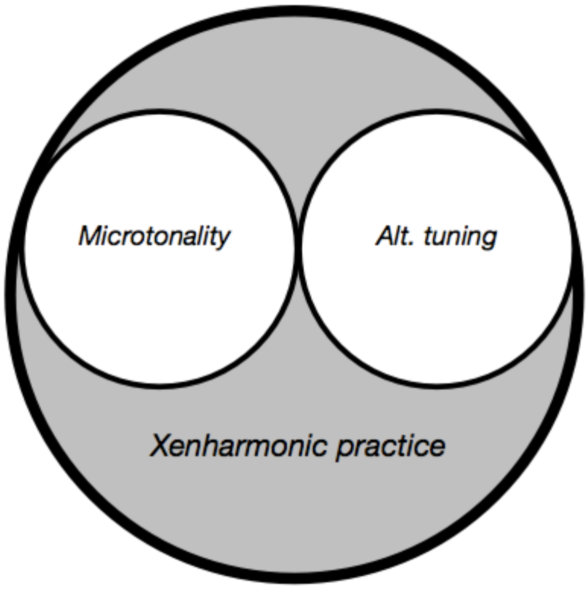


Figure 1: Diagram/model of relationships between different terms related to microtonality

This diagram assumes that non-microtonal alternative tuning systems are a separate category. It also allows that xenharmonic practice may comprise a larger totality than the sum of microtonality and alternative tunings, perhaps in the realm of harmony based on selective retuning of some harmonic partials in a structured fashion or exploratory musical practice based on the frequency-based structuring of combinations of inharmonic timbres.

---

3 Although alternate/alternative tuning is sometimes used in a manner which encompasses microtonality, I have chosen here to use it to exclusively denote non-microtonal practice.

Sethares (2004, p.6) discusses xenharmonic practice with the inclusion of *non-octave scales*—those which utilise intervals or compound intervals other than the octave as their structural base, e.g. Mathews and Pierce (Mathews et al. 1988, 1989), who utilise thirteen subdivisions of an octave-plus-fifth/perfect twelfth in the creation of a scale which was also independently discovered by Heinz Bohlen in 1978.[4] Such xenharmonic scales of alternative structures may occur in both diatonic (i.e. varying interval size) and chromatic (roughly standardised interval size) form and may imply different possibilities in syntactical structuring. It must also be admitted that some just intonation approaches (for example, harmonic-series-based tuning) can undoubtedly be used to create alt. tuning xenharmonic rather than properly microtonal scales, i.e. in the alternative tuning of intervals derived from the first twelve harmonic partials. However, contemporary compositional investigation of these materials which adheres to harmonic-series structures—e.g. much of the work of Glenn Branca (born 1948) and James Tenney (1939–2006)—does so in a manner which *includes* the deployment of the microtonal intervals from the higher harmonics in the series. Based on this division of tuning/scale construction phenomena, the present thesis will focus upon microtonal practice, although (non-microtonal) alternate tuning will occasionally be discussed (where aspects of this usage have relevance for microtonal practice).

However, this preliminary definition of microtonality is one which undoubtedly presents some problems—it is more of a negative than a positive definition (as, indeed, the term microtonality is more of a negative than a positive term). Nonetheless, this definition–by–opposition (microtonality as structural deviation from smallest standard

---

[4] This scale structure is commonly termed the Bohlen–Pierce (BP) scale.

scale division) does provide us with a definition which is relatively compact and immediately comprehensible (or, at least, provides the potential for intuitive conceptualisation) based on commonplace musical experience in Western musical cultures. The remainder of this thesis will set out to provide a fuller account of a theory of microtonal music and its manner of operation in relation to both ‘immediate’ sensory concerns and larger–scale structural schemas of relationships between materials.

1.3.2 Defining Pitch as a Psychophysical Attribute

Microtonality is dependent on the musical parameter of pitch, which is related to the physical attribute of frequency. The perception of pitch is the result of a combination of physiological and psychological processes which map incoming frequency information under certain conditions (periodic tones based on either single–frequency sinusoidal components or complex periodic vibrations) within a particular range (see further discussion on this latter point, below) to an internal (i.e. psychological) scalar representation. As such, it is the subject of a *psychophysical* relationship, whereby the perception of pitch (i.e. its positioning on a psychological magnitude scale) can be predictably related to an incoming frequency stimulus and vice versa. As Stainsby and Cross (2009, p.47) put it, 'pitch is a percept, measurable only by psychophysical investigation, and frequency is a physical quantity, which describes the periodic properties of a signal.’ As Moore (2004, p.195) notes, pitch is 'related to the repetition rate of the waveform of a sound; for a pure tone this corresponds to the frequency, and for a periodic complex tone to the fundamental frequency', although some exceptions exist to this. In partcular, in relation to the fundamental in complex tones, it is worth noting that in some cases the pitch will relate to the periodicity and not to any of the sound's energy necessarily being present at the fundamental frequency. In certain cases, a sound may be perceived with a pitch corresponding to the frequency of a *missing fundamental* or *residue* associated with groups of higher harmonics with a given periodicity relating to this missing fundamental frequency (Schouten, 1940, cited in *ibid.*., p.207).

These principles hold true for relating the pitch of periodic tones—i.e. those with harmonic (or mostly harmonic) components—which are without significant differences in level, as there is a small effect of amplitude of presentation on pitch (Terhardt, 1974, cited in Moore, 2004, p.205). Nontheless, allowing for these provisos, the pitch of a given tone with harmonic components can be varied in a relatively predictable fashion by altering the frequency of a tone (as defined by a frequency derived from the periodicity of a complex tone or the fundamental frequency, whichever is lowest) and the ratio of the lower frequency to the upper frequency thus defines a relatively consistent corresponding change in pitch, such that identical ratios for different frequencies produce identical perceptual results (pitch intervals) in a wide variety of cases, though within certain frequency limits. For example, tones which are related in frequency by doubling or halving are related in pitch perception by the *interval* of an octave, as long as the second tone is below 5 kHz (Ward, 1954, pp.372,380). Therefore our perception of the frequency continuum is broadly structured around logarithmic (base 2) scales. Moore (2004, p.227) notes that other recognisable intervals correspond to various simple (i.e. integer or nearly integer) frequency ratios.

1.3.3 Relationships Between Pitches and Concepts of Consonance and Dissonance

In musical contexts, the perception of pitch tends to take place in the context of the recognition of relationships between different materials with this attribute. These relationships may be categorised on the basis of different cases of sequential or simultaneous relationships. Although pitch is potentially derived from a continuum of frequency variations, human engagement with the phenomenon tends to apply a *discretisation* process, whereby it is mapped to a set of steps which subdivide the frequency space in which humans are sensitive to pitch. As noted above, the doubling or halving of frequencies relative to each other results in the interval of an octave. Materials which are related in such a fashion evoke the perceptual phenomenon of *octave equivalence*, whereby frequencies (and resulting pitches) which are related by such an interval will be treated as perceptually equivalent; see Shepard (1964). This landmark interval marks the beginning of human discretisation of frequency stimuli into a range of pitch intervals/categories. *Scales* are typically constructed by the division of the octave into a number of different intervallic subdivisions, whose pattern of division is generally repeated at successive octaves in human musical systems which treat pitch in an organised fashion. The exact rationale behind the choice of particular locations on the frequency continuum for these divisions is the subject of some debate within the musical literature, which will be discussed in detail in chapter five. However, for the present purposes a generalised explanation will be offered which is based on physical and physiological (and related psychological) factors.

The delineation of scale systems for a variety of human musical activities exhibits a great deal of convergence across musical cultures (such as those of Western, Chinese, Indian and Middle Eastern cultures) and the structure of scales within all of these musical cultures appears to be closely related to patterns based on the physical structure of the *harmonic series* (Burns, 1999, p.248). The harmonic series is an archetypal series of *frequency components* based on whole–number multiples[5] of a common fundamental frequency (or lowest component) within complex periodic tones. These frequency components (also known as harmonic partials or, for the sake of brevity, harmonics[6]) therefore possess a predictably simple generative structure and musical scales which are based on their relative positions may therefore be described by simple mathematical relationships. A discovery attributed to the early Greek mathematician Pythagoras of Samos (see section 1.3.1, above) derived scale steps related to this principle, based on assessing the properties of different lengths of a stretched string which are related by whole–number–based ratios, such as 1:2 (ratio for length, corresponding to 2/1 for its changed frequency) for the octave, or 2:3 (3/2) for another interval considered to have euphonic properties, the perfect fifth. Other intervallic subdivisions derived from transpositions (procedural movement) based on this latter interval are organised into a scale–based division of a single octave by taking intervals which exceed this limit and transposing them down an octave or compound octave. Intervals obtained by proceeding upwards in such a procedural fashion therefore provide lower–octave/within–octave transpositions of the harmonic series frequencies found in typical periodic tones. The followers of Pythagoras attributed the euphonic properties of certain divisions to the mathematical simplicity of their ratios, and therefore considered the

---

[5] i.e. two times, three times, four times a fundamental frequency, etc.
[6] For the sake of stylistic variety, all three terms will be found throughout this thesis.

structuring of musical pitch to be a branch of mathematics; see (Nolan, 2002, p.272; Benson, 2006, p.154) for further discussion.

The generally simple and predictable relationship between specification and what was considered to be euphonious could be viewed as the result of the physical manifestation of the simplicity of these ratios. This manifestation can be found in the time interval which it would take a pair of tones with frequencies related by these intervals to come back into synchronisation, producing the measure known as *periodicity*, with more mathematically complex ratios possessing higher periodicities. Therefore, musical scale steps which are related by these simpler periodicities may explain the euphoniousness of steps based on extremely simple ratios, such as the octave or fifth, versus steps based on more complex ratios such as 15/8. By the seventeenth century, the basis of such divisions in the frequency components of periodic tones had been established (Benson, 2006, p.140) and Rameau (1722, chapter 3) advanced a theory of harmony related to simultaneous combination of intervals which was based on the concept that matching interval specification to the earlier frequency components within the harmonic series resulted in more harmonious or consonant sonorous results. It follows from this that the more the frequency components (including upper harmonics) of two or more periodic tones match, the more consonant the result in terms of this sensory–based definition.

Helmholtz (1863) extended the investigation of consonance and dissonance in tone sensations into a physiologically–based theory, informed by his study of the structure of the human ear (Benson, 2006, p.141). Although he did not possess a fully accurate understanding of the exact functions of the internal structure of the ear, Helmholtz theorised that parts of the inner ear acted as resonators which were tuned to respond to different frequencies (due to different degrees of tension), therefore allowing for the spatially–based separation of incoming vibrations into different frequency components (Finger, 2001, pp.116–7), with dissonance being related to whether incoming vibrations contained frequency components which were close enough together to produce interference effects, known as *beating* or, in less coherent cases, heard as *roughness* (Benson, 2006, p.141). Following on from this, von Békésy (1960, cited in Handel, 1989, p.472) studied the physical response of the *basilar membrane*, a component of the inner ear which possessed the type of spatially–selective resonating response which Helmholtz had theorised (although he had incorrectly attributed its physiological origin), concluding that this was the physiological origin of Helhmholtz's resonator–based *place theory*. Thus, the perceptual phenomena of consonance and dissonance in musical tone relationships were theorised primarily from the perspective of physiological response rather than the formal properties of the source percept.

Plomp and Levelt (1965) investigated the psychophysical extent of this response whereby tone sensations for input frequency components turn from perceptually clear and/or euphonious to unclear/chaotic (based on the beating or roughness effects noted above), enumerating a response based on the *critical bandwidth* which indicated the physiological system's frequency resolution (hence, bandwidth) for clear tonal percepts for adjacent frequency components. As Roederer (2008, p.37) notes, overlaps within resonance regions on the basilar membrane result in confused tonal percepts, producing amplitude modulations which are perceived as the phenomena of beating (in certain particularly coherent cases) or roughness effects (where a number of such interactions are taking place quite vigorously and the perception of individual frequency components in perception becomes difficult. Since the critical band response extends over approximately 1/3 of an octave (*ibid.*, p.39), except in lower–frequency ranges, its limit is typically denoted by the minor third (which is perceived as a relative consonance, with intervals smaller than this typically being classed as dissonant in common practice musical systems).

The place theory model discounts the origins of consonance/dissonance percepts in the *exact* periodicity of frequency combinations; however, periodicity–based theories of pitch perception (known as *temporal theories*) coexist with the place theory in contemporary literature and Sethares (2004, p.44) notes that both aspects of auditory interactions may play integrated roles in the perception of pitch and related secondary phenomena such as consonance/dissonance judgements. Although the periodicity–based information may be significant in certain cases, the critical band response does account for many common features of musical experience, including the categorisation of intervals in common scale systems into degrees of relative consonance or dissonance (including the treatment of within–critical–bandwidth tones and semitones as somewhat dissonant in combination with other intervals). Thus, smaller intervals—such as those found in microtonal systems—by definition may be considered to be dissonant, with the result that intervals based on higher harmonic series intervals (which are smaller) may be expected to result in pronounced sensory–based roughness effects and thus may be expected to be of little musical utility if euphonious/clear results are intended.

However, the very perceptual distinctiveness of microtonal intervals may enhance their utility for musical structures which are expressly based on the creation of unusual sensory effects. In one conception, microtonal variations between materials may provide variants or *analogues* of familiar interval divisions, providing subtle variations in the relative dissonance of sonorities if presented simultaneously or, in terms of melodic quantisation, if presented sequentially. In addition, if presentational circumstances allow for the perception of periodicity–based effects such as beating to be prominent, microtonal intervals which induce such phenomena may be differentiated on the basis of rates and relative positions of beating frequency components. It should be stressed here that amplitude modulation of these beating effects may occur in relation to higher components in a harmonic tone and such interactions may induce perceptual segregation effects for these materials through the parsing processes of *auditory scene analysis* (Bregman, 1990), related to the tracking of differing modulation effects as being related to different auditory objects; cf. (Bregman (1990, pp.252–3, p.575) after (Chowning, 1981). Indeed, as will be discussed further throughout the thesis, other such perceptual parsing processes may also contribute to the creation of perceptually distinct cases resulting form the use of microtonal materials. Therefore, such materials may produce a range of sonorous results through their interaction with a range of perceptual processes (including critical band responses, the tracking of periodicity and their contribution to perceptual segregation or grouping processes), which may produce a significant degree of distinctiveness even for small frequency differences.

1.3.4 Models of Relationships Between Stimulus and Cognition

The nature of the relationship between the source stimulus and the processes entailed in the act of perception is a central one within the field of psychology. In engaging with this field, this thesis incorporates certain concepts which may require contextualisation for the music specialist. One key context is the division between more ‘basic’ (sensory) *perceptual* processes, such as those which explain the psychophysical correspondences between frequency and pitch, discussed in section 1.3.2, above, and more sophisticated cognitively–based processes of grouping and modelling of relationships between materials.

The modelling of perceptual processes can be described through relatively straightforward models based on the concept of *transduction*, whereby one modality is translated into another modality whilst preserving the original's structure. The study of pitch stimuli using this approach, psychophysics or, more particularly, psychoacoustics, was the subject of an extensive programme of research from the 1930s and 1940s onwards, see discussion by Shepard (1982, p.306) and Krumhansl and Shepard (1979, pp.579–80). This type of approach, which prioritises the study of perceptual transduction processes which are not the subject of more complex cognitive processes, may be termed a *bottom–up* process, whereby the structure of a percept is dictated by basic *sensory perception*. As such, whilst any act of apprehension of a stimulus may be termed 'perception', the present work will, where relevant, use *perception* in a narrower sense as relating to these bottom–up sensory transduction processes. However, the conscious perception of pitch based on these sensory processes is nonetheless still influenced by the structures of the human memory system; see Snyder (2001, 2009). One potential limiting factor suggested by early research is a limit in capacity of *short–term memory* for any single modality to around seven (plus or minus two) elements (Miller, 1956). This memory–based limitation on structured perception poses significant problems for cases such as microtonality, which uses a significantly greater number of scale divisions than this capacity would seem to accommodate, unless other factors are contributing to its structured perception; for example, through the association of parts of a stimulus with others, thus reducing the effective capacity required, a process which is known as *chunking* (*ibid.*, p.350).

However, Kurmhansl and Shepard (1979, p.580) and Shepard (1982, pp.306–7) identified the importance of other factors in the perception of pitch in musical contexts, relating to *top–down* processes which entail the relation of stimuli to *cognitive* models (which may allow for the development of relations between stimulus materials so that memory capacity limits are circumvented). In contrast to the psychophysical case, these place a greater emphasis on the mental processing which takes place after basic sensory perception processes have completed the transduction of stimuli, with Shepard (*ibid.*, p.310) opining that transduction is 'largely irrelevant' once it has taken place. Based on this division, this thesis will tend to favour separate terminology for these different perspectives on the perceptual act: *bottom–up* or *perceptual* for the transduction process and *top–down* or *cognitive* for the process of relating pitch materials to each other within more complex mental frameworks. However, it will not adopt Shepard's reductionistic position that the bottom–up transduction processes are irrelevant to musical experience, but will attempt to investigate a more unified model whereby both bottom–up and top–down factors may contribute to an explanation of how microtonal stimuli may relate to microtonal experience.

What top–down cognitive processes allow for, which bottom–up perceptual processes do not, is a greater role for contextual factors within perception as a whole. Indeed, Krumhansl and Shepard's (1979) investigation of musical pitch is posited on more global relationships between groups of materials which occur over time, rather than focussing on individual sequential intervals or those occurring simultaneously. Such an approach is essentially computational, in that complex internal models are built on the basis of relating the transduced structures to other such structures in memory, resulting in emergent formal models. However, the model–based cognitive approach is but one perspective for the treatment of context in the perception of pitch. In contrast, another approach, *ecological perception* (Gibson, 1966; 1979), seeks to place the environment at the centre of the quest for the nature and structure of perceptual processes. This assumes that structured perception is largely or, in the case of the originator's perspective, wholly based on environmental structures. The environment is assumed to be both information–rich and structured, as long as a multitude of perceptions/actions are explored in order to uncover environmental invariances or regularities. As Gibson himself put it, 'the available stimulation surrounding an organism has structure, both simultaneous and successive, and that this structure depends on sources in the outer environment […] the brain is relieved of the necessity of constructing such information by any process (Gibson, 1966, p.257, quoted in Shapiro, 2011, p.29). Thus, the ecological perception places the emphasis on structure back upon the stimulus itself without recourse to more complex analytically–based cognitive modelling of perceptual data (mental processes of *representation*), such as the processes espoused by Krumhansl and Shepard, above.

This perspective has informed other, less extreme, views than those of Gibson. The auditory scene analysis processes and principles defined by Bregman can be described as heuristics which take advantage of our reasonable expectation of certain *environmental regularities* (Bregman, 1993, pp.11–36), as organisms which are active within an environment. Thus, our perceptual experience is shaped by our ecologically–

informed expectations.[7] Our experience of music, from this perspective, is defined by its relative similarity to broader principles of environmental auditory organisation. A corollary of this ecological emphasis is that studies which do not take account of such contexts, whatever the stimulus, may be considered to provide little insight into the nature of perceptual processing and experience. Informed by this perspective, this thesis will query whether information from a range of domains and modalities may contribute to the structured perception of microtonal materials in representative musical contexts.

The embedding of an ecological context within theories of perception has also informed another strand of thought within the psychology field. *Embodied cognition* (Lakoff and Johnson, 1980; Varela et al., 1991; Clark, 2008; Rowlands, 2010; Shapiro, 2011) is a movement which seeks (to varying degrees) to embed, situate or connect the cognition of an agent in an environment to the environment's interaction possibilities. As Shapiro (2011, p.52) notes, the perspective of Valera, Rosch and Thomson (Valera et al., 1991)—whose text is a foundational influence on embodied cognition—was informed by the theories of Gibson (1966; 1979). However, the exponents of embodied cognition differ with Gibson in terms of the degree to which relatively complex cognitive models of the environment are formed as part of perceptual acts. Whereas the original Gibsonian perspective does not favour the creation of such cognitive models, embodied cognition offers a means by which cognitive modelling processes can still form structures of relative complexity.

In embodied cognition, the structures of cognition are considered to be based on components derived from environmental structures and/or the interaction possibilities in

---

[7] Handel (1989, xi) takes a similar, explicitly Gibson–informed view of auditory perception.

the environment. This may either entail the *replacement* (Shapiro, 2011, p.4) of representational processes for some key components of perception or the 'import[ing] of modes of reasoning from sensory–motor experience' (Lakoff and Núñez, 2000, p.xii). These 'imported modes' are termed (embodied) *image schemas* (Lakoff, 1987, Johnson, 1987, Lakoff and Johnson, 1999, p.77) and are abstracted versions of the interaction gestures which are typical of a thinking organism's interaction with an environment and which are then applied to the creation of cognitive models through *cross–domain mappings*[8] (Lakoff and Johnson, 1999, pp.57–8), either singly or in groups of such mappings. These therefore allow for the explanation of more complex thought processes surrounding perception and thus possess some of the potential benefits of more complex cognitive modelling processes, whilst providing an elegant solution to the problem of potentially significant cognitive load entailed in more traditional theories of cognitive modelling, such as those defined for pitch by Krumhansl and Shepard (1979). Furthermore, the integration of the analytical framework with ecological structures in a unified model may be of benefit in explaining the relationship between different component domains of a stimulus (e.g. pitch, timbre) and the overall structured cognitive experience which occurs in response to the stimulus.

This thesis will therefore investigate the question of microtonal music's cognitive–perceptual validity from a perspective which takes account of a wide range of theoretical models, whilst maintaining an awareness of the potential significance of ecological and embodied contexts in explaining the cognition of structure in the challenging perceptual circumstances which may be entailed by microtonal approaches.

---

[8] The function of mapping from sensorimotor to cognitive structures and processes in the context of embodied cognition.

The discussions in the chapters on earlier microtonal practitioners will take preliminary account of these contexts before a more comprehensive theoretical model is advanced in chapters five and six.

1.4 A History of Interval Definition: Music, Measurements and Mathematics

The exploration of various methodologies for the division of the octave is inherent to the problem of the specification of intervals and the construction of pitch–based scales. If we define the microtonal interval as the division of certain standard intervals, microtonal intervals are encountered as a byproduct of scale construction processes and, more generally, the comparison of intervals mathematically defined by frequency ratio. That such secondary byproducts of scale construction might become primary musical materials in twentieth and twenty-first century musical practice bespeaks a changing set of musical priorities and an investigative critical engagement with the canon of Western music theory on the part of practitioners. The microtonal composer, whatever their motivation (be it the search for novel sonorities or novel possibilities in the formal structuring of pitch) is generally by definition involved in the construction of scales[9] either through the subdivision of established intervals through various means; e.g. equal division of an established structural interval such as the octave or tempered semitone, or the use of a frequency ratio which corresponds to a small change in pitch.

This process of engagement has been facilitated by a number of factors: (1) new musical resources generated through technological development, (2) modernist, *avant-*

[9] Gestural/unstandardised use of microtonal inflections aside.

garde and experimental impulses in music, (3) cultural currents which imply a critical engagement with canonical assumptions and, perhaps most importantly, (4) procedures and conditions by which such assumptions can be interrogated, through developments in the separate fields of auditory psychology, computer-based composition and other experimental music and sound art practices which provide the conditions for the documented exploration of musical materials in relation to parametric and ecological (environmental/contextual) aspects.

In the history of Western music, what we would now recognise as microtonality is first encountered in relation to music theory based upon the 'language' of frequency ratios, rather than as an integral part of documented musical practice (until the late nineteenth and early twentieth centuries). Such theoretical antecedents are to be found in second–hand accounts summarising earlier practices and, as such, imply a great deal of ambiguity in relation to their connection with musical practice and the accuracy of accounts of their genesis. The following will provide a summary of what is currently understood about some of these precursors with reference to their relevance for later musical practice which foregrounds microtonal aspects.

1.4.1 Ancient Sources and the Pythagorean Scale

In relation to the mathematical definition of intervals and its influence upon Western musical practice, two historical-cultural antecedents can clearly be traced: ancient Chinese and Greek music theories. Partch (1947/1974) provides an alternative to the prototypical Western account in the section of his monograph which focusses on discussions of microtonality and frequency ratios. He speculates that historical cultures other than the ancient Chinese or Greeks (namely the Egyptians and the Assyrian-Bablyonians) may have theorised and/or experimented with music on the basis of interval ratios, though documentary evidence is not extant (Partch, 1974, p.361). However, China is cited as a documented example of a culture predating Classical Greece whose musical activities included such investigations. Though the exact provenance of this type of musical system is not of prime importance in the context of the present work, it is useful to summarise some of these antecedents as prototypical cases of mathematical definition and organisation for pitch-based intervals.

An early mathematical construction of a pentatonic scale is attributed to Ling Lun, a court musician under Emperor Huang-Ti, by Sima Qian, an early Chinese historian ca. 145 or 135 BC—86 B.C.E (Hardy, 1999, p.4). Partch references Sima Qian (transliterated as Sze Ma-chi'en) for a discussion of Ling Lun, noting that the date indicated in this source (twenty-seventh century BCE) is considered by modern scholars to be the subject of probable exaggeration (Partch, 1974, p.362). A more recent account by Kin-Woon Tong has discussed the possibility that—based on the etymology of the words in the name and the use of bells as tuning references—Ling Lun may, in fact, refer to musicians in general 'or more precisely as "bell player" and "pipe player"' (Tong, 1983, p.116). However, Partch discusses Ling Lun on the basis of his being a historical individual.

The pentatonic scale organisation attributed to Ling Lun derives a length of bamboo into 81 parts, obtaining frequency ratios of 1/1, 9/8, 81/64, 3/2, 27/16 and 2/1 (Partch, 1974, p.362). This type of scale, commonly known as a Pythagorean scale, anticipates the discovery attributed to Pythagoras of Samos (6th Century B.C.E.), where a musical scale is constructed on the basis of frequency ratios which are constructed with whole number multiples of three or less, bounded by an octave. In more familiar intervallic parlance, this scale comprises the root, major second, major third, perfect fifth, major sixth and octave to be found in Western common-practice music, though the third is of a somewhat different size and sonority in comparison with more modern conceptions of the interval. Such a scale is an example of a *three–limit* scale, so termed because it uses multiples of three or less to generate the frequency ratios of its intervals. The use of such a limited range of factors for the ratios may be connected with other aspects of ancient Chinese numerological thought, as is evidenced in this quote from the *I Ching*:

> In ancient times the holy sages made the *Book of Changes* thus:
> They invented the yarrow-stalk oracle in order to lend aid in a mysterious way to the light of the gods. To heaven they assigned the number three and to earth the number two; from these they computed the other numbers.
> (Shuo Kua/Discussion of the Trigrams: I, from the *I Ching* trans. Wilhelm and Baynes, 1968)

This scale specification was reprised or independently developed in ancient Greek music theory under the apparent auspices of Pythagoras of Samos. In a sixth century C.E. account by Nichomachus of Geresa, Pythagoras heard different tones which possessed audibly consonant interval relationships (such as the fifth, fourth and octave) emanating from a blacksmith's forge. On investigating, the story relates that the musical intervals obtained were found to be based upon simple integer ratios (Nolan, 2002, p.272). The mathematical basis of tuning with reference to the length of division of a sounding object (in this case, a stretched string) was then demonstrated on the monochord after this legendary (but presumably apocryphal) story of its initial discovery.

The primary interval of the Pythagorean scale is the fifth based on the frequency ratio interval of 3/2—see account in Benson (2006, p.154). This interval could also be thought of as the third partial from the harmonic series, brought back within a single octave. Scalar notes are determined based upon transposition by fifths, multiplied by 1/2 to bring back inside the bounds of the octave. Such fifth–based connections are considered by Western Music to be important and can be conceptualised as a *circle of fifths*. These integer-based ratios can also be said to be related to some intervals within the harmonic series, which describes harmonic vibrations, including those of periodic tones.

The entire Pythagorean diatonic scale is specified in frequency ratios as follows:
C (1/1), D (9/8), E (81/64), F (4/3), G (3/2), A (27/16), B (243/128), C (2/1).
As noted above, all of the ratios are within the 3–limit, as they involve multiples of three or less. The simpler ratios (3/2, 4/3, 2/1) are the 'founding' consonances which were effectively taken as corroboration by the Pythagoreans of the theory that the universe was ordered according to mathematical principles of harmony. In Pythagorean theory, numerical simplicity of ratios equated with musical consonance.

1.4.2 Pythagorean and Just Diatonic Scales Compared

However, based on this analysis, some intervals which were considered to be consonant (or relatively consonant) in later music take on a problematic form in the Pythagorean diatonic scale. The *E* above the *C* (major third) is of the form 81/64, which does not occur early on within the harmonic series, whereas another rendering of the major third (5/4) does. In the context of Pythagorean ideas of consonance and dissonance being related to the numerical simplicity of the ratios, the 5/4 interval would be considered to be relatively consonant, whereas the 81/64 is not. However, the Pythagorean attachment to the 3–limit scale appears to have precluded the latter. Pythagorean ideas of scale construction and musical consonance thus assume the use of 3–limit intervals as a key foundational principle, after which musical consonance and dissonance may be assessed by examination of the simplicity of frequency ratios. In contrast, Didymus in the first century B.C.E. and Claudius Ptolemy in the second century C.E. pioneered or transmitted the use of the 5/4 major third, based on a 5–limit (ratios as multiples of 5 or less) approach which effectively allowed for the use of a greater number of intervals which are directly derived from those found in the harmonic series—see Benson (2006, p.160) and Barbour (1951, p.2).

However, in spite of these earlier developments, medieval Western music theory focussed on the Pythagorean construction of the scale due to the manner of the transmission of Greek music theory to medieval Europe: Barbour notes that Boethius only discussed the Pythagorean approach in detail (Barbour, 1951, p.3) although a very brief account of ideas from Claudius Ptolemy's *Harmonica* is also provided (Kárpáti, 1987, p.30). Nonetheless, it is possible (indeed, probable) that actual musical practice may have favoured the 5–limit Ptolemaic approach before theoretical accounts admitted it: for more on this, see Barbour's discussion of the fourteenth century C.E. Walter Odington's contention in relation to singers intuitively preferring and utilising Ptolemaic tuning (Barbour, 1951, p.3). The increasing use of thirds during the fifteenth century in particular highlights its role as a more consonant interval (Covey-Crump, 1992, pp.318-

9). Van de Geer et al. (1962, p.317) note a possible explanation for the increasing use of thirds during the Renaissance in the sense that the increasing reduction of a multiplicity of modes to a major/minor dichotomy, with thirds occupying an essential role in establishing major or minor key identities. Whatever the rationale, in the context of the nascent polyphony/harmony of this period, it is plausible that the use of major thirds of an approximately 5/4 frequency ratio which would produce a more familiar (from the early reaches of the harmonic series) consonance would no doubt have been compatible with the treatment of third (and sixths) as relative consonances, the concept of consonance now related to degree of tonal fusion in addition to other aspects such as voice-leading (Tenney, 1988, pp.95–97).

Comparing the magnitudes of interval ratios provides us with an early case of frequency differences which are smaller than standard tones or semitones. Indeed, semitones could be conceptualised as microtonal alterations in relation to larger tonal divisions ('standard' tones) through their named identities deriving from modifications of heptatonic scale divisions—e.g. *F* and *F#*—in addition to the practice of tonal alterations in the case of Medieval and early Renaissance *musica ficta*. However, the primary motivation behind the analysis of intervals smaller than these standard scale-based steps was to measure distance in pitch between tuning approaches. Extremely small 'proto-microtonal' intervals such as the 81/80 *syntonic comma* were known by early theorists (Didymus and Claudius Ptolemy) as the difference between different types of interval (in this case, the 81/64 and 5/4 versions of the major third) but were not conceptualised in terms of melodic (i.e. structural) relevance. As such, they were the microtonal equivalent of *musica ficta* alterations, brought about either by the instrument maker or the performer, depending on the nature of the instrument (Darreg, 1975).

1.4.3 Generating the Just Diatonic Scale

As noted above, the use of 3–limit Pythagorean tuning of intervals appears to have persisted for a relavtively long period in Western musical practice in spite of the presence of alternative practices in the shape of 5–limit approaches to scale construction. However, it is probable based on historical accounts of theory and practice that there was an increasingly widespread use of 5–limit versions of the intervals of the diatonic scale during the Renaissance. This scale is defined as follows and is properly termed the 5–limit *just diatonic* scale:

C (1/1), D (9/8), E (5/4), F (4/3), G (3/2), A (5/3), B (15/8), C (2/1)

It can be generated after the method of Zarlino from 1558, reprising the ideas transmitted by Claudius Ptolemy (Loy, 2006, pp.60–1). Loy discusses its construction based on the frequency ratios 4:5:6 (see figure 2, following page) which define a major triad with the third being 5/4 times the frequency of the root of the note. The root is expressed as 4/4 instead of 1/1, with third and fifth being expressed as 5/4 and 6/4 respectively. The 6/4 fifth simplifies to 3/2, thus the prime number five is the highest prime factor used to describe any of the intervals above, thus the scale is a 5–limit scale. These triads are defined for the tonic, dominant and subdominant position, creating frequency ratios for all intervals within the diatonic scale.

c	**d**	**e**	**f**	**g**	**a**	**b**	**C**	**D**
4	**:**	**5**	**:**	**6**				
			4	**:**	**5**	**:**	**6**	
				4	**:**	**5**	**:**	**6**

Figure 2: Diagram of ratios which are the basis of the 5–limit diatonic (after Loy 2006, p.61)

This scale is one of a larger category of scales known as *just intonation* scales: those which can be expressed using simple integer ratios within a specified prime number limit. '5–limit just intonation' is sometimes shortened simply to 'just intonation', with systems involving integer ratios of other primes (e.g. seven, eleven, thirteen) sometimes termed *extended just intonation* (Kopiez, 2003, p.388).[10] 5–limit just intonation, based upon the overall scale structure described in the earlier theorists mentioned above—with the addition of chromatic divisions (Barbour, 1951, p.89; Haar, 1977, p.391)—can be found in Western musical practice by the sixteenth century (Barbour 1951, 93).

1.4.4 Modulation, Tuning Inconsistencies and Meantone Temperament

The application of just intonation to chromatic divisions exacerbated problems which would have existed even in the case of simpler diatonic implementations with fixed-tuning instruments (e.g. keyboards and fretted instruments). Although the tunings of 5–

[10] 3-limit just intonation is a special case and is generally simply named for the school associated with its origin, hence 'Pythagorean'. 5-limit just intonation is termed 'Ptolemaic' after Claudius Ptolemy, the earliest source of information on this approach.

limit just diatonic scales accurately adhered to simple integer ratios in terms of the generation of some intervals, others within the diatonic scale were irregular in size as a result of the scale generating process.

For example, the whole tones of the scale were of two sizes (e.g. *D* down to *C* = 9/8 divided by 1/1 = 9/8;
E down to *D* = 5/4 divided by 9/8 = 10/9), though semitones were of the same size. Major thirds, whose tuning was prioritised in the creation of this scale, are 'stable' at 5/4 for all of the diatonic intervals relative to *C*, but minor thirds were inconsistent (*F* down to *D* = 4/3 divided by 9/8 = 32/27;
G down to *E* = 3/2 divided by 5/4 = 6/5), with the former providing quite a complex ratio which would have produced a significantly different intervallic sonority. Most seriously, a major problem is encountered with one perfect fifth termed a *wolf fifth* (G down to C = 3/2 divided by 1/1 = 3/2;
A down to D = 5/3 divided by 9/8 = 40/27—wolf fifth), which is significantly different from the 3/2 ratios of other perfect fifths.

At its root, this problem stems from the fact that integer ratios which are not duple are not fully compatible with the 2/1 octave division. For example, in the case of the Pythagorean approach, tuning successive intervals on the basis of moving upwards by twelve 3/2 (perfect fifths) should equate with moving up by seven octaves to the same starting note—see Loy (2006, p.66). Moving in fifths, we have the series *C, G, D, A, E, B, F#, C#, Ab, Eb, Bb, F, C.* However, we uncover a discrepancy if we calculate and compare the two means of reaching that upper *C.* $(3/2)^{12}$=129.746, whereas $(2/1)^{7}$=128. Although this discrepancy, known as the *Pythagorean comma*, is relatively minor

(23.46 cents), it is indicative of the issue facing the tuning of scale notes if they are to form a 'closed scale system' as Loy terms it (*ibid.*, pp.66–7) which would facilitate moving to another tonal centre whilst still preserving standardised intervallic relationships. In addition, the Pythagorean approach has the added problem of creating pure fifths at the expense of the arguably more familiar (and numerically simpler) 5/4 ratio for major thirds. In contrast, 5–limit just intonation preserves 5/4 major thirds by prioritising their tuning as its main generative principle, but creates two different whole tones (10/9 and 9/8) in the process, with these intervals differing by the small interval of the 81/80 syntonic comma. This interval could be viewed as being a proto-microtonal interval in theoretical terms, but one which was of significance only in terms of the comparative relationship between larger intervals and not directly employed in the context of contributing to heard musical structures such as melodic or harmonic progressions. In addition to describing the difference between the whole tones, the syntonic comma also describes the difference between the two different types of fifth and two different types of minor third mentioned above. These *commas*, ‘errors’ or imperfections in the tuning systems occur in different places based on the intervals whose tunings are prioritised in scale generation, but they are nonetheless manifestations of an incompatibility between duple and other frequency ratio relationships.

To ameliorate this issue, a process of altering certain intervals, known as *tempering*, led initially to the modification of mathematically simple interval ratios of some intervals to facilitate a more consistent major third of close to 5/4 for fixed-tuning instruments when played in various keys. (In such an approach, the major third becomes the most important interval after the octave at the expense of making small alterations to the fifth.)

In short, the basis of this early[11] temperament is that the third is optimised by a relatively regular reduction in the size of the fifths built upon a number of different intervals. This approach became known as *mean–tone temperament.* Although a number of variations on this approach are possible, only the following approach is, strictly speaking, termed mean–tone temperament. This tuning scheme is based on the creation of two *mean tones* when a just intonation major third is divided into two equal parts (Covey-Crump ,1992, p.324). The following description is after Loy (2006, pp.64–5).

Following the approach used for the generation of a 5–limit just intonation, we proceed on the basis that major thirds (based on the 5/4 ratio) need to be established for three key scale degrees: C:E, F:A, G:B (i.e. tonic, subdominant, dominant). Establishing the size of the whole-tone degrees within these thirds is also required, this time for the fixing of the tuning of the intermediate steps within the thirds (C:D, D:E etc.). This temperament receives its name from the approach of simply dividing the 5/4 interval into two equal parts: mean tones. We obtain the following relationships (see figure 3, next page):

[11] At least, in the context of Western music.

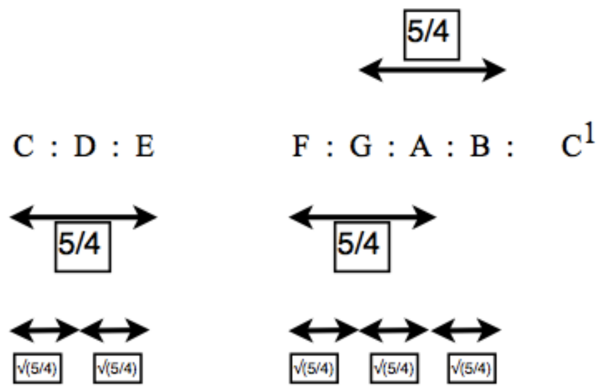


Figure 3: Diagram of interval relationships when generating a mean-tone scale after Loy (2006, p.65)

As can be seen from the above, splitting the 5/4 major third into two mean tones produces an interval of √(5/4) (which, when multiplied together with itself, produces 5/4).[12] The division of the major third into two equal parts produces a single whole-tone interval size for the diatonic scale, an improvement upon the just intonation diatonic in the context of melodic materials. Having obtained our whole-tone division (termed mean tone here due to its derivation), we need to create semitone steps for E:F and B:C. These semitones are again identical in size and therefore can be expressed as s^2 when added together (s standing for the semitone ratio). Given that the octave in the diagram above includes two semitones and five whole tones (in this case, the mean tones), the octave ratio of 2/1 can be expressed as follows:

$$s^2 * (\sqrt{(5/4)})^5 = 2/1$$

Taking the square root of both sides:

[12] The adding of individual intervals together requires the multiplication of their ratios.

$s*(\sqrt{(5/4)})^{5/2}=\sqrt{2}$

Then, isolating *s*, we obtain the semitone for E:F and B:C.

$$s=\sqrt{2/(5/4)^{5/2}}=\sqrt{2}/(5/4)^{5/4}$$

We now have an expression for the tuning of our semitones and, as noted above, this scale is more consistent than the 5–limit just intonation diatonic in terms of whole–tone and semitone sizes. However, this is at the expense of the fifth, which is no longer of the (very) simple 3/2 ratio.[13] Indeed, the above account does not fully elucidate the original method of early theorists and tuners, who obtained this temperament by tempering the fifth by an easily described value, one quarter of the syntonic comma (81/80), which produces the required 5/4 thirds for the diatonic scale. Benson (2006, p.177) describes it on the basis of flattening each perfect fifth in the cycle of fifths by a quarter of the syntonic comma (see figure 4, below), notating it using a method which highlights the multiples of a syntonic comma which are being applied as temperament.

	$\mathbf{E^{-1}}$	**:**	$\mathbf{B^{-5/4}}$					
$\mathbf{C^{0}}$	**:**	$\mathbf{G^{-1/4}}$	**:**	$\mathbf{D^{-1/2}}$	**:**	$\mathbf{A^{-3/4}}$	**:**	$\mathbf{E^{-1}}$
					$\mathbf{F^{+1/4}}$	**:**	$\mathbf{C^{0}}$	

$\mathbf{C^{0}, D^{-1/2}, E^{-1}, F^{+1/4}, G^{-1/4}, A^{-3/4}, B^{-5/4}, C^{0}}$

Figure 4: Diagram of meantone temperament by divisions of syntonic commas after Benson (2006, p.177)

[13] Indeed, this approach makes the semitone and whole-tone steps more dissonant (in the context of periodicity and simplicity of ratio).

As Sethares (2004. p.65) puts it, this system effectively works because 'a stack of four -1/4 tempered fifths gives a perfect 5/4', as can be seen in the case of intervals such as *C:E, G:B, F:A* above. It is an *unequal temperament*, since the sizes of the fifths vary (this is the price paid for the more generally regular tone and semitone sizes). In addition, the tuning of thirds will not be 5/4 in certain keys which are more remote from the original pitch reference along the cycle of fifths as more chromatic intervals are introduced, resulting in particularly poor renderings of these archetypal intervals in keys such as *C#* major, *F#* major etc. Again, as with 5–limit just intonation, the application of this practice was adopted gradually and there are a number of historical variants on this mean-tone temperament approach. The earliest documented account of 1/4 comma mean-tone was provided by Pietro Aaron in 1523, though in the context of fairly 'informal' tuning instructions (Rasch, 2002, p.202). A 2/7 comma meantone variant was pioneered by Zarlino in 1588 (*ibid.*), though this experiment gave rise to more significant intonation problems and was later repudiated by its originator (Barbour 1951, pp.32-3). An attempt to tackle the problem of minor thirds and major sixths gave rise to the 1/3 comma system of Salinas. Barbour criticises this system as producing somewhat inferior major thirds (and, obviously given the greater magnitude of the alteration, fifths), though its originator clearly considered these sacrifices worthwhile, noting of its alteration of the fifth that ‘although this imperfection is seen to be greater than that which is found in the other two temperaments, nevertheless it is endurable’ (*ibid.*, p.34). Intriguingly, it is also noted by Barbour that this approach prefigures more modern attempts to solve the 'intonation problem' through a version Salinas envisioned based on a 19-note division of the octave (*ibid.*, pp.34-5).[14]

The process of tempering intervals facilitated a growing interest in a wider range of modulations, requiring further experimentation in the tempering of intervals to deliver intervals which were usable in a wide range of contexts (i.e. keys). Although the various unequal temperaments noted above were investigated throughout the sixteenth, seventeenth and eighteenth centuries— see (Benson 2006, p.189)—a system of equal division of the octave into twelve chromatic intervals (12TET) eventually gained dominance in Western musical practice. This latter approach yields a scale in which modulation to keys based on all octave divisions produce consistent results, though at the expense of the precise specification of its intervals based on simple integer ratios (with the exception of the octave).[15]

1.4.5 Enharmonic Distinctions and Proto–microtonal Intervals

However, one alternative approach to obtaining something close to just intonation in a range of keys through the medium of keyboard or fretted instruments (fixed-interval-tuning instruments) can be found in the deployment of extra interval, essentially increasing the number of note-divisions within an octave. An analogous process had already given rise to an expansion of the keyboard interface from one based on the diatonic scale into our standard twelve-division keyboard to facilitate performances in a greater range of tonal centres, with the 1361 Halberstadt organ pioneering this approach

[14] Barbour notes with approval the lack of a poor or 'wolf' fifth or problematic thirds, though he finds problems with its implementation through a 12-note-division keyboard.

[15] It should be noted that one interesting exception to the adoption of 12TET in Western music was to be found in the case of the pipe organ, where practice tended to favour mean-tone tunings until the late nineteenth century (Lloyd, 1940, p.348; Doty, 2002, p.4). It may be surmised that the relative salience of upper partials in many pipe organ timbres would have the potential to increase the perceived some 12TET intervals.

(Keislar, 1987, 19). An early or pioneering instance of this 'secondary' or 'incidental' enharmonically–based microtonality can be dated to before 1484 and an organ in Italy with keys for *Eb* and *D#* and *G#* and *Ab* (Barbour, 1951, p. 107). Barbour notes a number of references to such multiple divisions during the sixteenth and seventeenth centuries in the work of Italian theorists, with separate/split keys for such intervals becoming finding use in common practice in Germany during the seventeenth and eighteenth centuries (*ibid.*). Helmholtz discusses the example of Handel performing on English organs which employed such an approach (Helmholtz, 1863, p.434).

Keislar (1987) notes that such designs provide an enharmonic approach to microtonal division which is not expressly intended as a means of increasing the vocabulary of pitch-based divisions. He further notes a variety of approaches to this keyboard interface 'problem' during this period, including split keys and the insertion of further divisions on successive manuals (Keislar, 1987, p.19). He coins the term 'accretion principle' to describe such keyboards which subdivide existing intervals whilst maintaining a similarity with the 'familiar pattern' of standard divisions, noting that its popularity in early keyboard instruments attested to its utility for a relatively small number of extra intervals. The problems of increasing difficulties in the execution of a performance through the medium of a keyboard interface possessing increasing complexity may have been one factor in a move towards consolidation of a smaller number of intervals which nonetheless preserve some of the chromatic 'accretions' for the purposes of facilitating modulation. In this context, the prototypical chromatic interface and scale design which eschewed enharmonic distinctions (pioneered by the 1361 Halberstadt organ), facilitated by the ‘technology’ of temperaments, eventually superseded the 'brute force' design approach of intervallic accretion.

1.4.6 Towards Equal Temperament

The variety of meantone approaches obviated the requirement of extra keys (or related devices) in fixed–tuning instruments in order to produce intervals which were reasonably close to just ones. Given that these microtonal variations on pitches were not intended to be utilised as categorically distinct in their own right, the 'accretion' approach (as it is termed by Keislar) was supplanted by an approach based on an investigation of the degree of temperament which could be accepted by musicians and listeners in return for enhanced possibilities in modulation and/or chromaticism.

Giovanni Maria Lanfranco provided rules for tuning organs, clavichords and fretted string instruments which may be considered to be an ancestor of the Western development of equal temperament (Lanfranco, 1533, cited in Barbour, 1951, p.55). This approach appears to be derived from the large thirds of Pythagorean tuning, with the instruction to flatten fifths and sharpen major thirds as far as possible without their sonority (and categorical validity) will permit. In this sense, a comparison of the earlier Pythagorean tuning of 81/64 for a major third with the 5/4 of just intonation may lead the former to be considered a 'just tempering' (i.e. integer-based tuning variation) of this interval category. One possible perspective on this is that the Pythagorean approach demonstrates that 'sharp thirds' can be musically acceptable and, therefore, a wider variety of experiments in temperament may be possible. In this light, the Pythagorean attachment to the 3–limit at the expense of an imitation of the harmonic series could be seen as paving the way for intervallic relativism and challenging intervallic essentialism.

Rasch (2002, p.207) notes that equal temeperament was familiar to sixteenth and seventeenth–century theorists (Zarlino, Salinas, Gallilei[16]) although its practical implementation was limited. However, in the context of theoretical texts, the earliest Western authority who hints at this type of approach is Aristoxenus (third century B.C.E.), who is frequently associated with theorising in this area by Renaissance theorists (Lindley, 1984, p.30).[17] His whole–tone division was obtained by subtracting a fourth from a fifth, with a semitone defined as being half of this, supporting a standardisation of semitone size. (*ibid.*, p.31). This prioritisation of a standard component interval size as opposed to an obsessive focus on the tuning of certain key consonances could therefore be seen as prefiguring a key feature of much later Western musical practice.

A common popular belief, now somewhat discredited, is that J.S. Bach's *Das Wohltempierte Klavier* (*Well-Tempered Clavichord*), the first book of which dates from 1722, is the 'big bang' of Western equal temperament in compositional practice (Benson, 2006, p.181; Duffin, 2007, p.44). Bach's temperament was considered to be a very close approximation of equal temperament by Barbour (1951, pp.195–6). However, Bukofvzer (1947, p.286) notes that Bach borrowed the term 'well–temperament' from Andreas Werckmeister, perhaps implying that the collection was composed for an irregular temperament, such as those proposed by Werckmeister.[18] The requirements of the collection, which seeks to explore all twenty-four major and minor keys available on a twelve-note-division keyboard instrument, clearly imply that some

16 Who used 17/18 or 98.955 cents as an approxmation of the equal temperament semitone.

17 Barbour, after Courant, notes that the earliest specific numerical approximations of equal temperament tunings are to be found from the work of Ho Tcheng Tien from 400 C.E (Barbour, 1951, p.55); Partch cites this development in his own account, noting that this predates developments in practical implementation in Europe by seventeen centuries. (Partch 1979, p.369)

18 Werckmeister's irregular temperaments are discussed in Barbour (1951, pp.161–2, 166–7).

means of compromise tuning which goes further than mean-tone tuning in its search for key-based (and intervallic) homogeneity. Williams (1983, pp.47–8) dismisses non-equal temperaments out of hand based on this lack of homogeneity. In contrast, Lindley (1985, pp.721–5) provides an approach which attempts to demonstrate connections with the work of theorists who were contemporaries of Bach, alongside some discussion of musical examples whose attributes are considered to favour unequal rather than strictly equal tempering. More recent work has investigated whether the looped drawings on the title page was intended to specify tuning; Lehman (2005, pp.1–10, 17) is one such prominent example which proposes an interpretation based upon 1/6th comma (mostly) and some 1/12 comma tuning offsets for tempering fifths, whilst also summarising much of the previous work on this area. Attempting to summarise a mainstream working assumption, Taruskin (2005, p.248) opines that 'Bach's own preferred tuning was probably not yet quite equal' and suggests that it may have been that of the Werckmeister temperament which permits some variation in the size of thirds for less frequently used intervals. Duffin (2007, p.148) asserts that Lehman's 2005 article has conclusively solved the Bach temperament 'mystery'. To provide a conclusion to the present discussion, Bach could hardly have composed such a collection for viable performance using meantone or just–intonation–based keyboard instrument tunings. He needed something *approaching* equal temperament for such an extenstive and systematic anthology which utilised a significant degree of chromaticism, even if the slight irregularities of the temperament may have provided a variety of sonorities for different tonal centres.[19]

---

[19] Benson (2006, p.182) makes this point in relation to a set of modulated variations in the roughly contemporaneous BWV 910 Toccata in F# Minor.

1.4.7 Standardisation and Fragmentation in Scale Construction Methodologies

The subsequent development of the symphonic forms and piano sonatas and concerti of the Classical period with their discrete and relatively rapid progression of modulations within movements can only have copper–fastened this prioritisation of a range of moduation possibilities over quality of interval, leading eventually to 12TET.[20] As Terry Riley has famously observed regarding such music, 'Western music is fast because it's not in tune' (Riley, quoted in Young 2002, p.76), a comment based on its use of equal temperament in contexts of relatively rapid (in comparison with some non–Western musics) articulation rates of notes, chord progressions and modulations between; c.f. Gann (1997b). From the eighteenth century onwards, the twelve note division of the octave became the dominant scale structure within Western music, with an increasing utilisation of chromatic intervals as structurally important scale notes in their own right throughout the nineteenth and early twentieth centuries. However, in keeping with the spirit of experimentation which would bring the complete dominance of a single common practice in Western music to an end, some practitioners and theorists began to investigate a greater number of divisions within the octave as structurally important scale materials. In doing so, some would use theoretical tools for the exploration of tuning/intonation and sonority, whilst others would extend the process of subdivision of tempered intervals still further.

---

[20] Temperament was only required by fixed-tuning instruments such as fretted or keyboard instruments, but undoubtedly exerted an influence on instruments with more flexible tuning through the requirements of ensemble performance and, perhaps, musical training.

1.5 Chapter Summary

This preliminary chapter has introduced the topic of microtonality via the provision of key contexts in relation to: (1) the definition and delineation of the term; (2) outlining the main approaches to the generation of such materials alongside historical contextualisation of these practices; and (3) the discussion of relevant theories from the field of psychology. It has outlined the main aim of the thesis as seeking to explain aspects of microtonal practice within contemporary music in a manner which is consistent with current models in the psychology of perception, offering a defence of microtonal practices from more normative assumptions which may derive from research which focusses on either very simple stimulus structures or from investigations of common practice musical approaches, which do not include microtonality. The research methodology has been discussed on the basis of its comprising the investigation of exisiting microtonal practice (and related theories of practitioners) from the perspective of psychological models, alongside a compositional component which is designed to inform the development and the refinement of a theory of microtonality as it relates to perceptual and cognitive processes.

Chapter 2: Tempered Microtonality and Hybrid/Compromise Approaches in Twentieth–century Western Music

This chapter will discuss the historical and thematic context of the strand of early twentieth–century microtonalism which is based on the subdivision of existing scale steps. It will examine some of the various claims for precedence within the early microtonal field alongside interrogating the assumptions behind the theoretical rationales of the early practitioners. In addition, it will examine approaches which seek a compromise between the ease of scale construction entailed by simple subdivision processes and a concern for the close approximation of just intonation intervals.

2.1 Equal Temperament Microtonality in Twentieth-century Western Music

As a result of the prevalence of 12TET (twelve–tone equal temperament) in Western musical thinking, early speculation and experimentation with microtonal materials was frequently based on the further subdivision of tempered intervals into a greater number of tempered intervals. American just intonation pioneer Harry Partch, no friend of temperament, remarks in relation to quartertones and similarly tempered divisions that they might be valuable as temporary expediences for the creation of 'new musical resources' (Partch, 1974, p.430). In this regard, it appears that the application of microtonal equal temperament provided a number of early twentieth century composers with a point of departure for the generation of new musical materials. Ben Johnston (another composer associated with microtonal just intonation) affirms this approach as 'the easiest practical method for getting more notes per octave' (Johnston, 1971, p.42).

The historical survey in this section is not intended to be exhaustive in its chronicling of twentieth–century composers working with microtonality; rather, it is intended to summarise key early developments and use them to shed light on the theoretical models which underpin some prototypical applications of equal temperament ideas to microtonal music. As such, the concentration will be on early pioneers and those who engaged to a significant extent with theoretical issues in equal temperament microtonality; composers who occasionally used Quartertones for decorative effect and did not engage in such theorising (Bartók being one prominent example) will not be discussed.

2.2 One Possible Beginning: Julián Carrillo's *Sonido Trece* ('Thirteenth Sound')

Julián Carrillo (1875–1965) was a Mexican composer-theorist and an early experimenter with equal tempered microtonal tunings, developing a system of quartertones, eighth–tones and sixteenth–tones. According to his own claims, he was the first to utilise such intervals, making unverified assertions that his experimentation began in 1895 (Madrid–Gonzalez, 2003, p.57)[21], although his though his first article[22] had apparently been written in 1922 (Carrillo, 1924, cited in *ibid.*, pp.41-3) and his first published theorising and performed microtonal compositions took place in 1924. His microtonal theories were dubbed *Sonido Trece* or the 'thirteenth sound', due to their role in extending the intervallic vocabulary beyond the standard twelve–tone division (Partch, 1974, p.426). Carrillo, in his pioneering article–based polemic on the subject,

---

21 Partch (1974, p.426) repeats Carrillo's claims, stating a genesis of Carrillo's system around 1895.

22 This article comprises a discussion of the composition of *Preludio a Colón* for a mixed chamber ensemble soprano, flute, two violins, viola, cello, harp and guitar (1924) following correspondance with a number of other composers who urged Carrillo to demonstrate his theories.

wrote:

> The evolution will keep its always-ascending march. WE ARE ON THE VERGE OF WITNESSING THE MOST TRANSCENDENTAL EVENT PRODUCED IN MUSICAL TECHNIQUE NOT ONLY SINCE THE RENAISSANCE OR THE MIDDLE AGES BUT ALSO SINCE THE TIMES BEFORE JESUS CHRIST. The 13th sound is coming [...] What is the 13th sound? In the logical order of my previous prediction, the thirteenth sound can not be anything else but the subdivision of the half tone.
>
> (Carrillo, 1924, quoted in Madrid–Gonzalez, 2003, p.44) [Capitalisation in original]

In other accounts, Carrillo was a little more specific than he is here. The curious apparent emphasis on a single ‘transcendent’ interval gives way, on further explanation, to the understanding that this 'thirteenth sound' is used as a shorthand for microtonal divisions in general (Bellamy, 1973, p.6). Carrillo coined the term after the first such new interval he discovered upon experimenting in 1895. Curiously, this was a 1/16th division of a tone, resulting in a possible 96TET (96 tone equal temperament) scale, rather than the more apparently obvious step of investigating 1/4 divisions. The tone in question was produced by stopping a violin string with 1/16th of the length required for a whole-tone rise in pitch above an open *G* (Carrillo, 1948, p.180). However, although this very small division was apparently his first discovery, Carrillo notes that he used quartertones in his early attempts to demonstrate microtonal materials and to train musicians (*ibid.,* p.181).

One aspect which is novel about Carrillo's approach to such subdivision is that his theories view the significance of even very minor alterations in pitch as being that they automatically create *entirely new pitch categories* which *possess distinct structural significance*. This leads to the assumption that any number of pitch divisions with perceptual and structural significance can be created through such a process (Carrillo 1954, p.131). This assumption is one which many microtonalists would have some affinity with, but is also one of the key bases upon which microtonal approaches have been subject to critiques from the perspective of psychology: whether all such intervals are indeed perceptually salient and structurally significant. These issues will be discussed in the second chapter.

A notable feature of Carrillo's theorising of the 'problem' of 12TET is the manner in which it relies upon theories of musical practice deriving from pure tunings. Based upon the conception of interval noted above, this presents a key problem. Carrillo himself stated '[o]bviously, teaching the theory of one musical system while another system enjoys common use is unforgiveable pedagogical malpractice' (Carrillo, quoted in Bellamy, 1973, p.8). His early theoretical text *Pre–Sonido Trece* (Carrillo, 1930) is subtitled a ‘basic rectification of the traditional musical system’ was an attempt to theorise on the basis of an assumption of equal temperament's essential (as Carrillo saw it) difference from just intonation. He makes the point that, based on the approximations inherent in equal temperament and their divergence from intervals derived from the harmonic series:

> Deliberately constructed to be mathematically inharmonic, the tempered system cannot accommodate any instrument employing harmonic sound [...] These instruments are consequently unsuitable for the tempered system used in music

today.

(Carrillo, 1930, p.49).

This insight is striking in its apparent prefiguring of the connection between spectrum and scale choice investigated by Sethares (2004), which will be discussed in chapter three. However, even more significantly for the present purposes (i.e. the central questions of this thesis relating to the perception and categorisation of microtonal intervals), Carrillo damns the 12TET system as containing no consonant intervals[23] due to its divergence from just intonation (Carrillo ,1930, p.60) and, on this basis, he attacks a music theory which bases its specification of intervals or ‘note names’—i.e. approximated interval categories—rather than on ‘the intervals themselves’—that is, more precisely specified intervals denoted by frequency or numerical indication of tuning ratio. Based on the working assumption of intervallic uniqueness discussed above, Carrillo appears to be emphasising the formal integrity of microtonal pitch divisions (due to a numerical integrity in specification) against categorical perception based on pitch proximity within a certain tolerance (which harmonic systems based on 12TET appears to 'assume'). Furthermore, Carrillo posits a theory based on the twelve–tone divisions as the salient structure rather than a (compromised) diatonic scale, emphasising that its mistuning leads to the invalidation of ‘traditional norms of chord resolution’ (*ibid.,* p.62).

Carrillo's move towards more atonal and microtonal composition led to the development of a system of notation which is based upon numbering equal divisions, with numerical placement in relation ot a horizontal line providing for the notation of register (Carrillo,

---

[23] Thus, establishing a stance which is against intervallic relativisim.

1930, p.68). The numbering system is not fixed but is related to the number of divisions which a given system of octave division will use. In the first two examples below (see figure 5(a–b)), standard 12TET divisions are notated using integers from 0 to 11. In the microtonal example (figure 5(d), following page), the numbers indicate a 96TET (sixteenth–tone–based) scale). Rhythmic notation is broadly similar to standard Western practice (figure 5(c), following page).

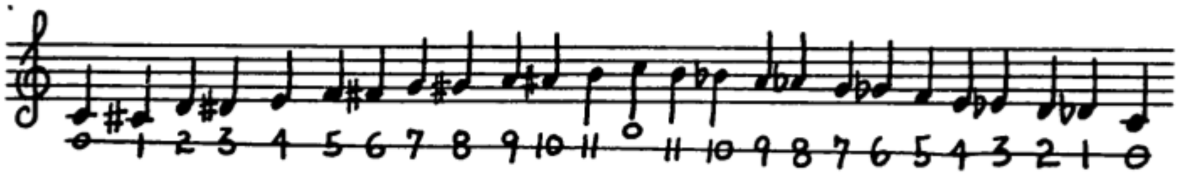


Figure 5(a): Standard notation of 12TET division of the octave, with Carrillo's notation below (Carrillo, 1930, p.70)

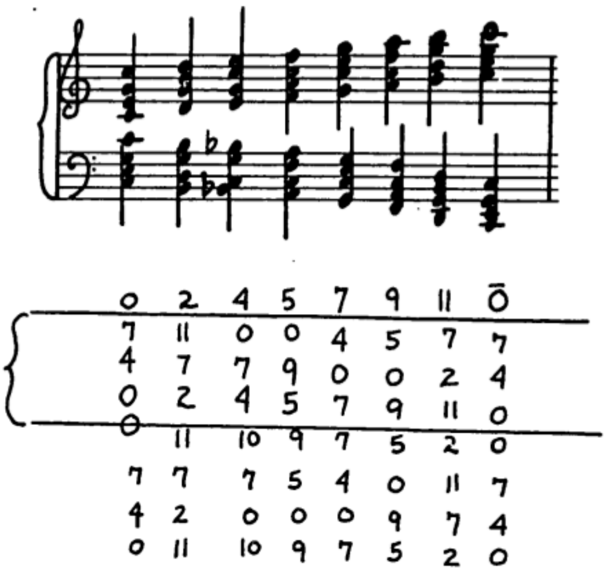


Figure 5(b): Standard notation of 12TET chords, with Carrillo's notation below

Note the use of position above, below or centred on horizontal lines to denote register, with the *lower line in this case denoting the octave at middle C (pitch 0), with other intervals taking their place above and below this line in a vertical list configuration (Carrillo, 1930, p.72).*

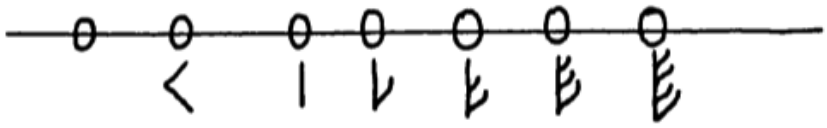


Figure 5(c): Rhythmic notation in Carrillo's new notation system

Key: (from left) semibreve, minim, crotchet etc., with the 'notehead' being the number of the pitch in terms of the chromatic naming convention (Carrillo, 1940, p.380).

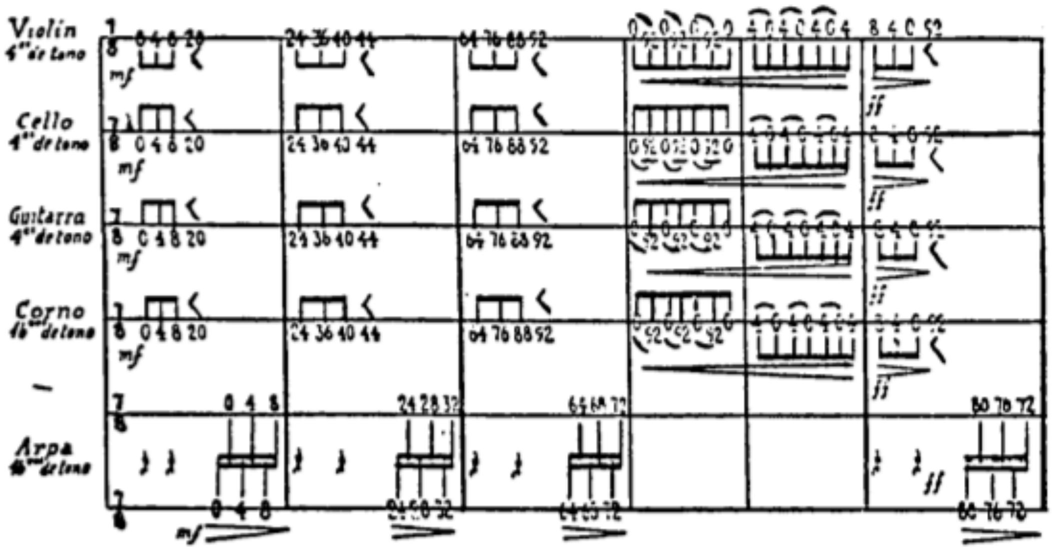


Figure 5(d): Notation of Carrillo's 1927 Concertino

This uses approximations of sixteenth-tones for the notation of pitches derived from the harmonic series (from Carrillo 1940, p.393).

This system allows for the easy notation of multiple divisions whilst avoiding what Carrillo would consider to be erroneous associations with the note categories of earlier musics. The notational element of Carrillo's work is one which he regarded as of central importance, not only in the facilitation of his own microtonal work, but also in providing for a range of musical activities (Carrillo 1954, p.79). This system certainly does have the beneficial property of being flexible and easily extensible in relation to equal-temperament-based microtonality. Later in this work, Carrillo provides a table outlining its application in a variety of equal division systems of microtonality from third-tones to sixteenth-tones (*ibid.,* p.94). He further notes possibilities in relation to equal division of the octave (as opposed to the more 'intuitive' microtonal approach of the subdivision of the established semitone) into intervals ranging from ninety-five per octave to five per octave (*ibid.,* p.121).

One aspect which should be noted is that in spite of Carrillo's attack upon intervallic relativism and lamentation regarding the divergence of 12TET from an accurate adherence to the acoustic bases of Western music's harmonic system, he did not approve of the 'pure tuning' impulse either, attacking the Pythagorean system (and, by implication, related systems) on the basis of its being practically unfeasible for fixed-tuning instruments in cases where modulation is important (Carrillo 1948, pp.174–5). Curiously (for a microtonalist), he seeks support for his perspective in the shape of a quote from Rameau regarding the difficulty of discerning the difference between a 10/9 and 9/8 tone, though he later hints at this issue being possibly related to some sort of inertia in the public mind (and ‘ear’) regarding novel intervals rather than necessarily providing a clear-cut case against microtonality (*ibid.,* pp.175-6). Although he discusses 'natural' scales (based on integer frequency ratios), these are invoked merely to reinforce the divergence of established performance practice from this ideal and to reinforce his argument in favour of chromaticism and (presumably) permutationalism in musical structures. Curiously, Carrillo appears to balance himself between these two poles (influences drawn from the harmonic series and microtonal chromaticism), with explanations for approxmations of third–tones (27/26) and quartertones (36/35) as intervals between adjacent harmonics (*ibid.,* p.203). However, he also notes here that the harmonic series is structured around intervals which are unequal rather than equal, thus negating one of the key bases of not only equal temperament but also historical Western musical thought. A further renunciation comes when he unambiguously addresses the question of categorical equivalence of various intervals which differ in frequency:

> Any given musical pitch is obtained from an exact number of vibrations produced isochonously within a determined period of time. With an increase or decrease of the number of vibrations, the result *is not the same pitch but another pitch*, absolutely different from, and without 'accidental' relationship to, the original.
>
> (Carrillo 1948, p.208). [italics mine]

Thus, although the concept of his microtonal equal temperament intervals as being similar to intervals within the structure of the harmonic series is initially invoked, such intervals themselves, in Carrillo's conception, appear to be more fundamentally related to an extensive chromaticism rather than a *tonal–harmonic* approach. This ambiguity is resolved as it becomes clear in the section entitled ‘Musical Advances’ that although Carrillo himself favours equal-temperament-based chromaticism in practical/pragmatic terms, he regards *Sonido Trece* system as itself allowing for the creation of a range of systems based upon either tempered or natural divisions (*ibid.,* p.214). He also anticipates a ‘sonorous arithmetic [...] since each number represents a tone, any numerical quality can be musical', presumably entailing some sort of permutation-based aid to composition (*ibid.,* p.215), alongside a possible refinement may be based upon his harmonic-series-influenced conception of dissonance as related to materials derived from higher harmonics (*ibid.,* p.212). Indeed, it should be noted that a relatively early 'breakthrough' piece, his *Concertino* of 1927 (performed by the Philadelphia Orchestra under Leopold Stockowski), utilised pitches from the harmonic series as material—sixteen odd-numbered harmonics derived from the series of the first to thirty-first harmonics (Carrillo, 1940, p.347).

The external influences (if any) which led to the early development of Carrillo's system (and the chronology of its early development (and practical usage) are somewhat unclear: Madrid–Gonzalez states that professional opponents noted the theorising of Busoni[24] and Schoenberg and the compositions of Hába as evidence that Carrillo was not an innovator in the global context (Madrid–Gonzalez, 2003, pp.50–60). In this regard, the latter composer is significant with particular reference to his early string quartet compositions of the early 1920s, which signalled the beginning of the implementation of a microtonal approach in his compositions (Racek et al., 1965, p.198). The early date of 1895 provided by Carrillo as his 'myth of origin' could perhaps have been a response to these charges (Madrid–Gonzalez, 2003, pp.50-60). However, even if this were to be the case, Carrillo's early advocacy of a greater range of microtonal divisions, coupled with his extensive engagement with the practice of microtonal composition from 1924 onwards marks his work out as pioneering.

[24] Whose theorising regarding third-tone divisions is discussed in *Pre-Sonido Trece* (Carrillo 1930 trans. Bellamy 1973, p.47).

How extensively Carrillo's structural ambitions for microtonality were realised is perhaps debatable; there is certainly a degree of naivety attached to the assumption noted above—from (Carrillo, 1948, p.208)—that any change in pitch creates a new pitch category which does not possess any connection with the previous pitch category. Madrid-Gonzalez provides a Schenkerian analysis of the prototypical *Preludio a Colón* (Carrillo, 1924) which he uses to assert that 'microtones take part only on the foreground level, again as non-harmonic elements, passing notes within larger prolongations of tonal centers' (Madrid–Gonzalez, 2003, p.55). The description of the use of microtones as chromatic passing notes and aids to prolongation of a 'central' pitch is quite damning in relation to Carrillo's assertions regarding the structural possibilities inherent in microtonal organisation and the focus upon scalar structures in the quotes cited by Madrid-Gonzalez is undeniable (*ibid.,* p.49). However, the reductionistic aspect of the decidedly non-microtonal Schenkerian method of analysis means that it may not be the best tool to examine microtonal practice. The assessment from Madrid–Gonzalez above does not necessarily invalidate Carrillo's use of microtones any more than it invalidates any other more ornamental approach to melodic contours (even back to melismatic figures in modal counterpoint). Certainly, the opening demonstrates the perceptual salience of intervals as small as eighth–tones in the context of melismatic figures and extended contours.

However, the composer does rely on such contours to 'join the dots' between cadential axes with traditional harmonic implications (e.g. tonic to dominant)—e.g. (Carrillo, 1924, 0'17-1'50)—clearly an approach based on foreground concerns. Nonetheless, the harmonised scalar three-quartertone sections provide a clear introduction to what might be considered a xenharmonic approach (effectively based on an alternative division of the octave with larger interval structures) which does not easily reduce to common practice scale norms (Carrillo, 1924, 8'29 onwards). Thus, even if Carrillo is not always fully successful in establishing a fully distinctive microtonal practice in this early work, he does clearly engage in the experimental deployment of a variety of pitch divisions which are perceptually distinctive and, in the case of the three–quartertone elements, a break from previous practice in terms of scale structure. A work from 1927 which illuminates Carrillo's approach still further is his *Concertino* (Carrillo, 1927), illustrating a significant degree of international success through its commissioning by Leopold Stockowski for the Philadelphia Orchestra (Bellamy, 1973, p.35). As mentioned earlier, this work utilises pitch materials derived from the first thirty–one intervals of the harmonic series, rendered using sixteenth–tones. However, although these materials are used to generate pitch divisions, the structure of the piece owes more to an early twentieth–century chromaticism (indeed, at the opening based on semitones rather than microtones) than the tonal centeredness implied by any formal structure derived directly from the harmonic series. Microtonal materials are introduced from 1'28", again at first in scalar presentation before microtonal motivic melodic and scalar structures are further developed.

Overall, Carrillo's early compositions provide us with some examples which clarify some of the apparent contradictions in his theoretical work for the modern reader. For example, his invocation of the harmonic series as a structure relevant to microtonal composition is on the basis of the extension of pitch divisions of the octave as materials rather than any approach which anticipates the use of the form of the harmonic series to dictate compositional structure (for example, in the French Spectral school of the later twentieth century). Indeed, although his frequently extended melismatic microtonal contours and discretised glissandi are striking validations of the perceptual salience of such materials—i.e. the simple ability to perceive them in a musical context—his usage focusses on their deployment in contexts which are not particularly innovative (i.e. in sections with clear tonal harmonic implications or more chromatic/atonal motivic units). Indeed, his theoretical work arguably raises more questions that it answers conclusively. After its broaching of some intriguing possibilities in relation to contradictions between theory and practice in much preceding Western music, it settles down to a more pedestrian account primarily focussed upon a justification of its method of notation and the means by which further microtonal materials may be obtained (whilst only providing some hints as to the rationale by which such materials may be organised, in effect expressing sympathy with both the just–intonation–based 'natural' approach and equal-temperament-based chromaticism/permutationalism which are only resolved upon examining his compositions). It is only on examining his compositions that the ambiguity is resolved such that it is clear that Carrillo's theoretical position is based primarily on the 'subdivision impulse' relating to a search for a finer degree of quantisation for the representation of pitch; any discussion of the tuning of harmonic series intervals is only of passing concern, invoked to validate his point regarding subdivision. This suggests that his theories possess a greater internal consistency when examined alongside his music than might appear to be the case at first glance. Carrillo has, after all, made statements[25] which imply that he is the ultimate interval/tuning anti-relativist, so much so that he, in effect, becomes the ultimate interval/tuning relativist, as the general cases of microtonal chromaticism through scalar and motivic melodic structures are substituted for the particular cases of common practice functional

---

[25] See the following quote, noted previously from Carrillo (1948, p.208): 'With an increase or decrease of the number of vibrations, the result is not the same pitch but another pitch, absolutely different from, and without 'accidental' relationship to, the original' [italics mine].

harmony and as the mistuning of intervals is taken to render earlier theories of harmony invalid.

In spite of the problems of ambiguity in his exposition, the possible naivety of his extreme position regarding interval/tuning relativism and the extensive digression regarding his notation system, Carrillo is nevertheless a significant early theorist who explicitly recognised a variety of motivations behind the impulse towards the creation of microtonal musics. In particular, his work appears to recognise both the ‘subdivision impulse’ (behind microtonal equal temperament) and the ‘recreation of *natural* intervals’ impulse (although the latter is used used primarily to discredit the application of historical theories of harmony to contemporary tempered intervals and to support the ‘subdivision’ argument). In the more prosaic argument surrounding historical precedence of microtonal usage, even leaving aside the attestations to his system’s originality— extracted from various embassies and conservatories around the globe via a friend in Mexico’s diplomatic corps (Carrillo ,1948, pp.289-93) and whose efficacy and relevance can therefore probably be discounted—extant evidence relating to musical practice appears to be clear in according him priority in his investigation of 1/16 tones/96TET.[26] Most importantly, in spite of Carrillo’s propensity for overstatement, he nonetheless correctly identified some key issues in relation to microtonal practice. In cases where he was incorrect in his assumptions, he posed some hitherto unasked questions which had the potential to move the debate, its attendant definitions, and musical practice forward and provide the modern reader with one of the

[26] The New York press reaction to his work is cited by Bellamy as providing independent attestation to the novelty of this approach. (Bellamy, 1973, p.45). In addition, a letter from fellow early microtonalist Ivan Wyschnegradsky (see section 2.5), that Carrillo's work enjoys historical precedence over the likes of Busoni, though on the basis of how extensive his microtonal work was rather than corroborating the aforementioned 1895 genesis (Wyschnegradsky, quoted in Bellamy 1973, p.41).

most 'ecumenical' accounts of theory from an early twentieth-century microtonalist.

As Madrid-Gonzalez (2003, p.42) notes, '[f]or Carrillo microtonality came as the result of a pure [sic] theoretical concern based on a historicist view of the Western music tradition'. Here, the teleological ethos of modernism is assumed to inform Carrillo's desire for new sonorities to demonstrate a measure of progress in Western musical practice. This ethos would be shared with Busoni (in relation to his speculations on microtonality) and found common ground with some of Schoenberg's theorising along these lines. That said, the assessment of Carrillo's microtonality as stemming purely from this theoretical basis is possibly questionable—whilst a modernist ethos of experimentation and search for novelty certainly appears to have informed his engagement with this field, his early experiments, if occurring in 1895, predate his more extensive theorising by some time. Nevertheless, the key aspect of this particular genesis of microtonality was its search for new materials and the offering of some sort of rationale for a resulting change in musical systems, with a possible extra imperative for this development drawn from the cultural conditions of the new state of post-revolutionary Mexico in the 1920s (*ibid.,* pp.70,72).

Schoenberg, as noted above, had speculated about the possibilities inherent in the exploration of new intervals derived from the further reaches of the harmonic series in his *Harmonielehre*:

> We must yet strive for everything that is left over: the precise accommodation of all overtones, the relation to roots, eventually the formation of a new system.
>
> (Schoenberg, 1922, p. 320)

He further takes issue with the definition of dissonance inherent in functional harmony, noting that 'there are, then, no non–harmonic tones, no tones foreign to harmony, but merely tones foreign to the harmonic system' (Schoenberg, 1922, p. 320). His most explicit discussion of microtonal possibilities, however, comes in an appendix where he discusses tempered divisions greater than than those of 24TET (quartertones), asserting that:

> it is clear that, just as the overtones led to the 12–part division of the simplest consonance, the octave, so they will eventually bring about the further differentiation of this interval. To future generations music like ours will seem incomplete, since it has not yet fully exploited everything latent in sound, just as a sort of music that did not yet differentiate within the octave would seem incomplete to us. (*ibid.,* p.422)

Whether Schoenberg's speculations directly influenced Carrillo's is unclear, but his thinking in this regard shares Carrillo's basis of a teleological assumption of historical progress and a modernist's desire for new musical materials, along with a similar initial justification of the basis of novel intervals as drawn from the harmonic series (albeit in tempered form).[27]

---

[27] Though, as mentioned above, Carrillo ends up settling on a position where tempered and untempered micrtonal divisions exist as separate systems which are made possible by the general microtonal 'revolution'.

2.3 Busoni's Sketch of a Microtonal Approach

Another influential early thinker on microtonal possibilities in music was Ferrucio Busoni (1866–1924) and his speculations on the possible uses of microtonal materials in music can be clearly seen as stemming from his strongly modernist ideology. At the outset of his ‘Sketch of a New Esthetic of Music’ (1911), he laments that none of the currents he discerns in the musical practice of his contemporaries ‘lead *upward*’ [italics in original], setting out his preference explicitly with the sentence 'The Modern and the Old have always been' (Busoni, 1911, pp.75-6). He marks out the common practice theory of harmony as problematic, noting that:

> So narrow has our tonal range become, so stereotyped its from of expression, that nowadays there is not one familiar motive that cannot be fitted with some other familiar motive so that the two may be played simultaneously.
>
> (*ibid.*, p.88)

At the centre of his argument is the contention that the prescriptive aspects of the tonal system select a narrow range from the multitude of possibilities inherent in pitch/frequency–based variations, becoming overly prescriptive in relation to consonance and dissonance:

> 'How strictly we divide “consonances” from “dissonances”—*in a sphere where no dissonances can possibly exist!*' (*ibid*., p.89) [italics in original]

Busoni appears to attribute the discretisation of pitches to the role of keyboard instruments and 12TET ('Nature created an *infinite gradation – infinite!'* (*ibid.*) [italics in original], noting in passing the lack of 'purity' of such intervals, memorably describing the 12TET system as 'diplomatic' and 'an invention mothered by necessity' (*ibid.*). Thus, he cites both of the main rationales in relation to microtonal practice but does not appear to choose between the two. He also references the lack of variety in scale structure of the Western major/minor system, invoking the concept of 'novelty of interval', noting the restrictiveness of the major/minor dichotomy in relation to emotional expression (*ibid.,* p.90), and proposing a system of variations in scale structure upon the diatonic scale, which, he asserts could yield 113 different scales (before transposition is taken into account), though he does not provide explicit detail in this regard (*ibid.,* p.92). Later in this essay, he is more explicit on the subject of his proposed microtonal system, stating that he wishes to 'draw a little nearer to infinitude' of interval through microtonal practice (*ibid.,* p.93). In contrast to the initial point of departure for many early twentieth century microtonalists, Busoni advocates the exploration of third–tones, noting that, whilst they would cause the loss of the minor third and perfect fifth, that they would offer possibilities for a 'refinement in chromatics', in spite of the problems they would cause for the rendering of the established sonorities noted above (*ibid.*). Such issues would, however, be addressed through the establishment of sixth–tone divisions based on semitonal offsets between pairs of third–tones (*ibid.,* p.95). In addition, he makes the further suggestion here that the performance of such intervals could be facilitated through the application of controls on electric instruments, citing the potential example of Thadeaus Cahill's Telharmonium/Dynamophone (*ibid.*).

Whilst the roots of Busoni's motivation are by now quite obvious and the practical aspects of implementation has been addressed, the detail of the functional rationale for his demands remain a little unclear. The prospect of more intervals is almost taken on faith as simply being a positive aspect of a new musical system, with little discussion of the connection between the 'infinite gradation' discussed above and the utilisation of third-tones (presumably the rationale simply being one of pragmatism, though this is not clearly stated). Implicit in his discussion is the role of such intervals in providing chromatic alterations to pitch–based contours. There appears to be a proto–atonal ethos inherent in the comment that 'no dissonances can possibly exist'. The discrepancy between this statement and the concern for 'purity' of intervals is confusing: is he implying that a wider range of consonances are possible within the realm of just intonation–based small intervals, with dissonance relegated to a function of tuning accuracy rather than utilised as an axis for the arrangement of musical materials?[28] Or is he reprising a Pythagorean concern with purity of interval in relation to melodic relationships between notes?[29] In either case, his proposed system would not deliver completely pure intervals, but would certainly deliver some measure of accuracy in the rendering of just intonation intervals, whilst offering greater pitch resolution for melodic contours and the possibility of extending chromatic harmony. The aspect of a greater range of expressive possibilities in chromatic melody and harmony seems to tally most closely with the rest of his discussion (see discussion of scale structure), with the concept of intervallic purity being partially satisfied by an increased number of tempered intervals yet remaining grounded within the foursquare ethos of musical structure implied by equal temperament. In one sense, the mention of 'purity of intervals' is something of a *non sequitur*, invoking the venerable naturalistic ethos admitted as explicit (but partial) justification of previous theories of Western music, though in a similarly non–binding fashion. That said, Busoni does appear to be concerned with the application of better approximations and an examination of music

---

[28] Such a position would anticipate the theories and practice of American composer La Monte Young.
[29] See discussion of Tenney (1988) in chapter four.

theories in the context of critical listening. The categorical validity of sub–semitonal divisions is asserted after his own experimentation (in addition to his aforementioned wish to 'draw a little nearer to infinitude'). In this sense, his speculations appear to offer something of an early link between the two main currents within microtonal thought: the tempered subdivision and the just–intonation–based interval.

2.4 Alois Hába and Chromatic Equal Temperament Microtonality

The Czech composer Alois Hába (1893–1973) was one of the most prominent composer–theorists of early twentieth–century tempered microtonalty. His *Neue Harmonielehre* (Hába, 1927) was subtitled 'des diatonischen, chromatischen, Viertel–, Drittel–, Sechstel–, und Zwölftel–Tonsystems', or 'the diatonic, chromatic, quartertone, third-tone, sixth-tone and twelfth-tone tonal systems'. As such, the connection to chromatic approaches is made clear in the title. Werntz (2001) characterises this approach as 'featuring conjunct melodic progressions', following on from a practice based upon microtonal inflection, though noting that features which may be viewed as ornamentation do not necessarily indicate a developed microtonal language/system (Werntz, 2001, pp.174, 177). The chromatic–melodic aspect of Hába's microtonal genesis is corroborated by his formative influence in 'archaic melodic types of East Moravian folk music' which incorporated microtonal intervals (Racek et al., 1965, p.198). Werntz, highlighting aspects of common ground between 12TET and microtonal chromaticism, notes the influence of Hába's teacher, Austrian composer Franz Schrecker, who influenced him towards a chromatic writing style (Wertnz 2001, p.183). Furthermore, Racek et al. (1965, p.199) note the parallel significance of Hába's twelve–tone output. Another major influence during Hába's early stay in Vienna (1918-1920) was the music of Schoenberg (Battan, 1980, p.7). Following a move to Berlin (influenced by his teacher Schrecker), a meeting with Busoni in 1923 further kindled Hába's interest in microtonality, resulting in the composition of his Fifth String Quartet in a Busoni-influenced sixth–tone system (*ibid.*, p.11). American microtonal composer Ben Johnston has opined that Hába's microtonality was influenced by Balkan folk music and was an attempt to approximate (and theorise) these novel intervals based on a finer division of a pitch-based grid (Johnston, cited in Duckworth, 1995, p.125).

Hába's microtonal approach was pioneered in his string writing, with an earlier mature quartertone–based composition being his Third String Quartet of 1922 (Racek et al., 1965, p.198). Crucially, in terms of potential influence, he was also an early microtonal pedagogue, and upon his return to Prague proposed the formation of a Department of Quarter–tone Music at the Prague Conservatory in 1923 (*ibid.,* p.199), though Battan highlights an interpretation of events that this department was not constituted on an official basis until 1933 and that the presence of his course on microtonal music was a source of some contention at the conservatory (Battan, 1980, p.14). Leaving such matters aside however, in relation to a comparative chronology in connection with the work of Carrillo, above, Hába's published theorising—with many articles which would later contribute to his *Neue Harmonielehre* appearing in the early 1920s (*ibid.,* p.27)—and teaching activity and, indeed, early mature microtonal compositions are either subsequent to or roughly contemporaneous with Carrillo's early work.

The construction of quartertone instruments also preoccupied the composer for some time until the late 1920s, with an early focus on an altered piano after a split–key–style keyboard design by Möllendorff and constructed by Grotian-Steinweg (Battan 1980, p.19). This first design utilised a double frame and double set of strings, but was not completed rapidly enough for Hába's liking, resulting in a new design which utilised a single frame and, in a crucial difference, a triple-manual keyboard, with the highest manual doubling the lowest manual's pitches, simply being present to facilitate ease of fingering in difficult passages (*ibid.,* p.20-1). Other microtonal instruments which were constructed include a harmonium, clarinet and trumpet, with the emphasis for his microtonal composition shifting to piano, voice and chamber compositions and culminating in a quartertone opera entitled *Matka* or *The Mother* (1929-30), which utilised a chamber orchestra with these instruments in addition to vocal soloists and choir (Racek et al., 1965, p.198). Late compositions included a further series of string quartets including quartertone–based works (Sixth, Twelfth and Fourteenth String Quartets) and sixth–tone pieces (Tenth and Eleventh String Quartets) during the 1950s and early 1960s (p.198).

Hába's theorising was more grounded in functional harmony than Carrillo's was (thus bearing more of a relation to Schoenberg's *Harmonielehre*), with a strong early focus on the incorporation of quartertones in functional–harmonic structures (Battan, 1980, pp.29–35). In addition, much of his early theorising was related to noting the relationship between the harmonic series and 12TET intervals (*ibid.,* pp.35). The microtonal aspects of harmonic series structure are used to justify the deployment of quartertones[30] (*ibid.,* p.75), though this is largely a justificatory invocation which does not intend quartertones to serve as significantly better approximations of harmonic series intervals. Instead, their primary function derives mainly from functional concerns for tension and release, with quartertone–baed chormatic alteration accentuating traditional (functional) axes of consonace and dissonance, with chords containing quartertone intervals being treated as more unstable (*ibid.,* p.36). Hába treats the

[30] Hába goes on to cite what he considers to be probable instances of quartertones in ancient Greek and ealier Western muiscs, alongside Arabic music and Slovakian folk music, although the assessment of these microtonal intervals as exactly quartertone-based is most likely reductionistic and somewhat inaccurate.

addition of extra intervals on the basis of its being *bichromatic* rather than *ultrachromatic*, effectively consisting of two semitone-based chromatic scales a quartertone apart rather than one single 24-note chromatic quartertone scale (*ibid.*). In addition to the role of quartertone–based chords in building up patterns of tension and release being familiar from the harmony textbooks of earlier eras, the quartertone modification of some intervals (such as major and minor thirds, sixths and sevenths) provides for 'neutral' variants between these oppositional axes (*ibid.*, p.36-7), providing regions of relative functional stability. To summarise his approach, Hába's text could be regarded—as Mandelbaum (1961, p.139) puts it—as 'a simple catalogue of scales and sonorities in each of several systems of equal temperament', but it is nonetheless one which highlights some significant functional potentials of the new materials.

In essence, Hába draws a connection between half–tone chromatic practice and that which incorporates quartertones, as noted above, treating the chromatic intervals as transpositions and allowing for their use in largely semitone–based melodic contexts (at quartertonal offsets) or in a harmonic context—frequently as dyads, as vertical structures are viewed by him as aggregates of dyads (Haba, 1927, cited in Battan, 1980, p.75-7). In the second case, melodies may utilise the quartertone materials. He also posits a new 'pure' quartertone music where at least one interval from the new quartertone selection is included in each dyad (*ibid.,* p.79). Similar principles are followed in the establishment of a third–tone and sixth–tone–based language and no new information about these materials is introduced beyond that of their notation (*ibid.,* p.83).[31] One key aspect underlying all of this work is that Hába considers there to be a

[31] A constant focus of investigations into microtonality is the problem of notation—witness also

strong element of continuity between quarter–tonal practice and established concepts of tonality, even if augmented by polytonality (*ibid.,* p.82), as illustrated in mature pieces such as his Op.62 Sonata for Quarter–tone Piano (Hába, 1947), which effectively superimposes quartertonal chromatic elaboration on a clearly tonal superstructure in a major tonality, with frequent recourse to traditional cadences.

Hába's theorising is more methodical than that of Carrillo, though it has a narrower conception of what might constitute microtonal practice (based solely upon tempered subdivision rather than considering any possibilities regarding just–intonation–based microtonality). Hába's microtonality can therefore be viewed primarily as an extension of the tension and release axis of late–19th– and early–20th–century functional harmony and his conception of microtonal practice does not problematise this functional aspect of harmony to the same extent as Carrillo's polemical (though somewhat inconsistent and unresolved) theorising.

2.5 Ivan Wyschnegradsky and Functional Approaches to Quartertones

Another notable early twentieth–century microtonalist was the Russian Ivan Wyschnegradsky[32] (1893–1979). His mature microtonal work dates from 1920 (following emigration to Paris) and he pioneered a form of notation derived from

---

Carrillo's focus upon this issue (to the occasional exclusion of other issues), in addition to the primary focus of Gardner Read's survey of microtonal practices, *Twentieth Century Microtonal Notation* (Read, 1990).

[32] His surname can also be transliterated as Vyshnegradsky, Vyshnegradski and Vishnegradski (Sitsky, 1994, p.248).

standard accidentals (Read, 1990, p.19) which, as Skinner (2006, p.14) notes, provide a prototype for the quartertone notation used in contemporary software notation packages such as Finale and Sibelius (see figure 6, below), resulting in this form contributing to a *de-facto* modern notational standard (although some aspects of this format derive also from Hába's notation in relation to microtonal flats).[33]

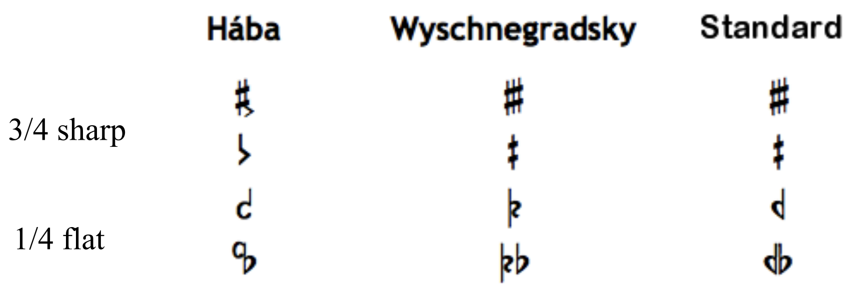


Figure 6: Early microtonal notation and contemporary standardised form (the notational standard in the Finale and Sibelius notation packages), adapted from Skinner (2006, p.14)

However, although his compositional activity using microtones dates from the point of his emigration to Paris, it should be noted that it arguably had its roots in his Russian cultural milieu and educational experience, with Arthur Lourié, a commissar at the Russian Department of Education, having previously composed a quartertone string quartet in 1910 and Georgy Rimsky–Korsakov having founded a society for quartertone music in 1920 (Roberts, 2002, p.543).

[33] The first chapter of Read (1990) discusses a variety of approaches to quartertone notation without discerning a particular standard (in the context of a survey whose materials predate the widespread use of software notation packages).

Like Hába, Wyschnegradsky developed a concern for the construction of suitable keyboard instruments, with a successful instrument being completed in 1929 by the firm of August–Forster (*ibid.*, p.544). However, due to various logistical difficulties, he subsequently fixed on a solution of using two standard pianos with tuning offsets to obviate a scarcity of performers who could engage with the new quartertone instruments, as he noted in an interview with Charles Amirkhanian (Wyschnegradsky, 1976, 25 mins). Indeeed, Wyschnegradsky also had a clear conception of microtonalism as an extension of equal temperament chromaticism and, as such, termed his practice *ultrachromaticism*, based on duple subdivision of the established 12TET intervals (Wyschgradsky, 1972, cited in Beaulieu, 1991, section 1). He also highlighted the 'equivalence' of equal temperament intervals based on their equal spacing, thus prioritising a functional view of their usage. In terms of the organisaiton of these new materials, Mandelbaum (1961, p.143) traces 'contradictory strains' in his theorising, on the one hand celebrating the novelty of microtonalism and on the other hand attempting to provide some degree of integration with existing music theory, epitomised by a concern for voice leading and concern for cyclical structures of modulation based on intervals such as 'neutral thirds', created by quartertone offsets between major and minor thirds, and microtonally altered 'major fourths': perfect fourth augmented by a quartertone (*ibid.,* p.148–9). Furthermore, Wyschnegradsky rationalised the demand for microtonal divisions partly on an extension of the leading note concept, suggesting that a notated major seventh is better rendered a quartertone sharp and opining that historical practice provides a precedent for microtonality through similar *musica ficta* modulations of established intervals (*ibid.,* p.152).[34]

Mandelbaum (*ibid.*, p.144), summarises Wyschnegradsky's 1932 theorising[35] as being comprised of two major units: (1) quartertone–based alterations to notes and chords and (2) the use of these materials as the basis for modulation within a fairly traditional harmonic framework. An example of this approach's somewhat deriviative nature (or, viewed more kindly, common ground with previously established theories) can be found in his voice–leading directions such that non–harmonic ornaments in the new (quartertone–offset) twelve note scale should be within less then a 3/4 tone of their resolution in a clearly tonal context (Wyschnegradsky, 1932, p.6, cited in *ibid.*, p.145). Scale structures are built in a fashion which has a much older lineage: the use of disjunct tetrachords and other (larger) modular structures (*ibid.,* pp.148–9). These modular structures provide for a degree of diatonic-style delineation of different scale areas—'Diatoniscized Chromaticism' (Sitsky, 1994, p.250)— which somewhat contradicts the assertions above regarding equality of equal temperament interval. In terms of the functional usage of his new materials, Wyschnegradsky, like Hába, conceived of his microtonal materials as providing for a new class of intermediate interval steps between existing intervals in the context of chords. His 'major fourth' is between the perfect and augmented fourth; the 'minor fifth' is between the perfect fifth and diminished fifth. The major fourth is considered to be an important interval in this system since it approximates the 11th harmonic or 11/8 frequency ratio (Skinner, 2006,

34 According to my own definition at the start of the thesis, such altered intervals would simply entail a xenharmonic scale. However the focus here is on finding a precedent for the use of quartertones, and such alterations, if consciously compared with the default versions of these intervals, would provide an example of a salient microtonal interval. Nonetheless, Wyschnegradsky does not provide any evidence (nor does he specify potential ancient musical cadidates) for this microtonal *musica ficta*.

35 Mandelbaum cites a publication date of 1933, but this is contradicted by Beaulieau (1991)—I adhere to the date in the more recent source in citations from Mandelbaum.

p.146). Such intervals are deployed in the context of neutral triadic constructions in which the *outer* interval is altered but the major/minor third at the centre is not, alongside a ‘neutral’ triad in which the perfect fifth is equally divided into two neutral thirds (Wyschnegradsky, 1932 cited in Mandelbaum, 1961, p.146).

The system of modulation to new keys derived from quartertone divisions is the other key plank of his theory, with recommendations such as the use of ornaments from the scale to be modulated to paving the way for modulation, with a further direction that larger intervals between different scale types be avoided (Wyschnegadsky, 1932, cited in *ibid.*, p.147). The modular generation of non–octave–based scales is also discussed. Furthermore, Beaulieau (1991, section 2) notes the contribution of the modulating intervals mentioned above to the process of scale construction, citing the example of a scale constructed on a series of Wyschnegradsky's major fourths, folded back within a single octave. Beaulieau (*ibid.*) goes on to note a relatively large number of such scales are facilitated by further subdivision of the semitone to a limit of one twelfth–tone.

An approach based on the treatment the new microtonal melodic materials as consisting of new scales with diatonic properties structured around duple–division–offsets from the standard semitone is common to both Hába and Wyschnegradsky. Indeed, a partial summary of Wyschnegradsky's theoretical approach is that, in a similar fashion to Hába, he resolves the issue of incorporating microtonal materials through an extension of chromatic functional harmony (through to polytonality), substituting quartertones for semitones and thereby creating new intermediate scale roots and both ornamental and functional microtonal motion to guide modulations to scales built on these new, intermetiate divisions of the octave. Although there is some similarity in their theoretical frameworks, the differences, such as Wyschnegradsky's aforementioned interest in formal properties of scale division, cause him to compose music which is much more atonal than Hába's as he deploys his cyclical microtonal modulations and scale structures, one example being his Op.45 *Étude sur les Mouvements rotatoires*, roughly translated as *Study of Circular/Cyclical Movements* (Wyschnegradsky, 1961). His compositional approach shows a degree of consistency, as his earlier Op.22, *24 Préludes dans l'échelle chromatique diatonisée à 13 sons*[36] (Wyschnegradsky, 1934) also uses cyclical structures to generate his scales, constructued from a cycle of his microtonally augmented 'major fourths', resulting in thirteen pitches being used from the 24TET scale (Skinner, 2006, pp.144–8). As Skinner notes, the irregular spacing of semitones and quartertones in this scale creates a type of diatonic scalar structure, though one which is not related to the standard heptatonic major scale. Based on his exploration of scale structures which do not have structural associations with traditional/Common Practice tonality but nonetheless possess diatonic properties, Wyschnegradsky's music has a degree of idiomatic syntactical clarity amidst its unfamiliar functional harmonies. In fact, this scale can be analysed in terms of both its microtonal scale and xenharmonic properties—the alternative diatonic scale structure produces a syntactical logic which is different from standard tonally-based music—thus it is a case of xenharmonic music which goes beyond 'simple' alternative tuning in terms of its alteration of intervals. As such, it charts something of a middle-path between traditional forms of tonality on the one hand and early twentieth-century serial structures on the other.

[36] Roughly translated as *Preludes in a 13–tone Chromatic Diatonic Scale*.

Wyschnegradsky's approach to his novel materials was clearly rigorous and internally consistent, but its xenharmonic scale structures and functional approaches engender a defamiliarising effect which is perhaps only partial. On repeated exposure, the clear syntactical/formal structuring of his pieces provides a structural aid for listening which, nonetheless, may not have been enough to help to foster a positive wider reception, notwithstanding the obvious logistical difficulties associated with the pioneering of microtonal matierals. (Indeed, for all of Hába's advantages of being a staff member at a national conservatory, he did not produce a significant group of microtonal proteges.) Unfortunately, Wyschnegradsky's distinctive formalist/syntactical approach does not appear to have fostered any subsequent developments which were a direct result of his theoretical work and relatively extensive compositional catalogue. However, later composers in his adopted base of France showed some degree of interest, with Boulez being the most notable interested party, though this interest may have been due to Wyschenegradsky's use of new instruments in the shape of the *ondes Martenot* rather than his espousal of microtonality (Roberts, 2002, p.545).

2.6 Ives and a Prototype of Perceptually–informed Microtonality

This section title is intentionally ambiguous, as two people with the surname Ives played developmental roles in American microtonal music. Charles Ives (1874–1954) is the more famous one, but he frequently acknoweldged the debt owed to his father, George Ives (1845–1894), a bandmaster and teacher who, according to his son, showed distinctly experimental and microtonal leanings. In his posthumously edited and published autobiography *Memos* (Ives, 1972), Charles Ives testified to the musical experiements conducted by his father, both with his band and privately at home, including experimentation with microtonal tunings (Ives, 1972, pp. 236–7). These experiments appear to have been quite extensive and systematic, if the testimony of the younger Ives is accepted. These include an array of 24 violin strings in quartertone steps, used to demonstrate quartertone melodies and inform quartertone singing exercises for family members (though Charles Ives notes that enthusiasm may have been limited with the exception of melodies with a significant diatonic element). He also stated that his father's quartertone experimentation began at least partly as a result of inspiration derived from the tones of a nearby bell, i.e. a timbre with discrete inharmonic complexes heard by George Ives as a novel chord (Ives, 1925, pp.110–11).

This view of the elder Ives as an experimentalist is not immediately apparent from local press coverage from Danbury, Massachusetts, but an extant manuscript containing part of a pedagogical article provides some insight into his musical explorations (Eiseman, 1975, p.142). According to Eiseman (*ibid.*), in this article, George Ives demonstrates a critical engagement with mainstream ninteenth-century music theory which could plausibly inform the experimentalism described by his son. This theory is criticised from the perspective of contemporary practice, with criticisms of the terminology for chordal structures (e.g. the terminological equivalence of various types of dominant chord) and the anachronistic naming convention for musical pitch which fails to fully treat each chromatic note as a unique identiy (*ibid.,* p.144–5); c.f. Carrillo's concerns in this regard. Such a concern for the treatment of chromatic pitch divisions as unique identities could clearly prefigure their further subdivision to form new microtonal identities. Furthermore, a reference to the 'partial' dissonance of the 7th arguably prefigures an interest in the consonant treatment of intervals deriving from higher harmonics:

> this 7th note produces what all musicians call a dissonance but sounds in some cases to me only like a partial dissonance and is used so much that we get used to it and treat it as if it were as much of a consonance as our other tones.
>
> (Ives, G., quoted in Eiseman, 1975, p.145).

The testimony of Charles Ives goes further in attesting to his father's experimentalism and makes explicit reference to microtonality: 'Father used to say [...] if the whole tones can be divided equally, why not half tones?' (Ives, 1972, p.140).

In addition to the potential status of George Ives as a founding figure of microtonal experimentalism (according to this combination of his own writings and his son's testimony), Charles Ives himself also left a small but significant body of early American microtonal composition and theorising about microtonal music. In an essay ‘Some "Quarter–tone" Impressions’ (Ives 1925, pp.105–119), Ives details inspiration derived from his father's work and questions derived from the work of Helmholtz[37] (Boatwright, 1969, p.106)). As Wolf (2003, p.5) notes, the Ives essay is a little ‘impressionistic’ and vauge, but it makes a number of pertinent observations in relation to perceptual issues which can be summarised as follows.

> (1) Quartertone–based triads tend to be heard in relation to more familiar triads and are therefore heard as out–of–tune versions , such as a *C–G* with a quartertone–offset–*D#*. (Ives, 1925, p.111).
>
> (2) Chords of four–plus notes may ameliorate this problem if they add an

---

[37] Via an article by William Poole (a London-based engineer, composer an University of London examiner according to Boatwright.

interval with a quartertone offset from a non-offset dyad such as *C–G* (*ibid.,* p.112).

(3) Largely diatonic melodies (with quartertone–based embellishment via passing notes and suspensions etc.) are accepted on the basis of a familiarity with diatonic idioms, though this approach is highlighted as avoiding the question of the viability of microtonal materials (*ibid.,* p112–3).

(4) A chord of five equal five–quartertone intervals (quartertone flat minor third, with the exception of the final octave interval) is held as meeting the requirements of a 'native' quartertone–based chord which contains fruitful harmonic possibilities, theorised as being analagous to a minor chord. (*ibid.,* p.113–4)

(5) Sensory dissonance is heavily dependent on amplitude (*ibid.,* p.114).

(6) That quartertone–based chords do not possess the same degree of implication codified by familiarity that standard diatonic chord progressions do (*ibid.,*p.115).

(7) Quartertone–based materials may continue to coexist with some form of tonality/(functional) harmony (*ibid.,* p.117).

(8) Psychoacoustical effects: Ives describes the result of playing a complex of whole-tone triads (augmented triads) in chromatic steps across two pianos tuned a quartertone apart, distributed over a number of octaves (*ibid.,* p.116–7). The resulting cluster containing all twenty–four quartertone intervals is held to be 'not especially harsh' and is described as producing various beating effects and a sound 'similar to the sounds one hears on putting the ear close to telegraph pole

in a high wind' (i.e. the harmonic series).[38]

As can be seen from the above, Ives shows evidence of being a rigorous experimenter–theorist who was open to the deployment of novel microtonal materials and alive to their compositional possibilities and relevant perceptual issues, resulting in an early and prescient engagement with key questions of quartertone-based microtonal practice. The focus on pyschoacoustics/perceptual issues is unusual for an early microtonal theorist (Wolf, 2003, p.5) and contrasts with the focus of Hába (1927) and Wyschnegradsky (1932) in relation to their focus on an increased number of intervallic permutations available within a framework derived from functional harmony.

Ives made a brief compositional contribution to microtonalism through his *Three Quarter–tone Pieces* of 1923–4, in addition to writing quartertone sections for piano and strings in the second[39] and fourth movements of his Symphony No. 4 (completed 1916)—see discussion in Brodhead (1994, pp.391, 407).[40] In the eponymous quartertone suite, the more minimal instrumental resources allow for a clear impression of Ives' usage of these materials. In this usage, they serve to add expressive enhancements to already dissonant chords, add finer degrees of pitch quantisation to melodies in the second piece (the *Allegro*) in particular and to chord progressions more generally, frequently producing pronounced changes to the sonority of chordal complexes in many sections. A particularly clear example is the dissonant opening of

[38] The presence of easily perceptible materials relating to the harmonic series when microtonal clusters are deployed has been engaged with extensively in the practice of later microtonal composers such as Phil Niblock (born 1933), so it is interesting to see that Ives as the early American pioneer of microtonality was already engaged with such issues in an essay from 1925.

[39] E.g. from rehearsal no. 36 and following.

[40] It should also be noted that there is some degree of confusion, possibly even controversy surrounding the dates of composition of some of the composer's works; e.g. see Solomon (1987, p.454). Berman (1999) also discusses the issue of dates in programme notes accompanying a recording of the *Three Quarter–tone Pieces*, noting however that these were based on earlier drafts of 1910–14.

the *Largo* which commences with some bell–like chords/complexes which are richly inharmonic (referencing the genesis of his father's interest in the area), see figure 7, below:

Figure 7: Composite and reduction of the opening chord progressions (without melodies) in the Largo *from* Three Quarter–tone Pieces *(Ives, 1924)—originally intended for a dual–manual piano*

However, what this (traditional) representation of the chordal does not make entirely clear is what might be termed the 'sonorous logic' of this opening. It is arguable that the sensory novelty of the microtonal chords dominates over more traditional elements of functional harmony. As such, a representation based on the timbral/sonorous aspects of these chords will be explored with particular regard to this use of tuning and configuration of materials (figure 8, below, succeeding pages). Based on the harmonic number notation[41] in figure 8(a), the chord appears to be designed to produce a significant degree of beating via what migth be termed *primary interactions* (between lowest components of individual notes) and *secondary interactions* (between the lower components of one note and the partials of another note), due to the proximity of individual notes to given harmonic series intervals.[42]

---

41 In some cases, a range of harmonic numbers which the notes potentially approximate, although the audible beating effects will only highlight the relatively low harmonics.

42 A piano tone will exhibit a degree of inharmonicity due to the high tension of the strings, producing a progressively stretched harmonic spectrum. However, the lower partials are still close enough to

Chord one

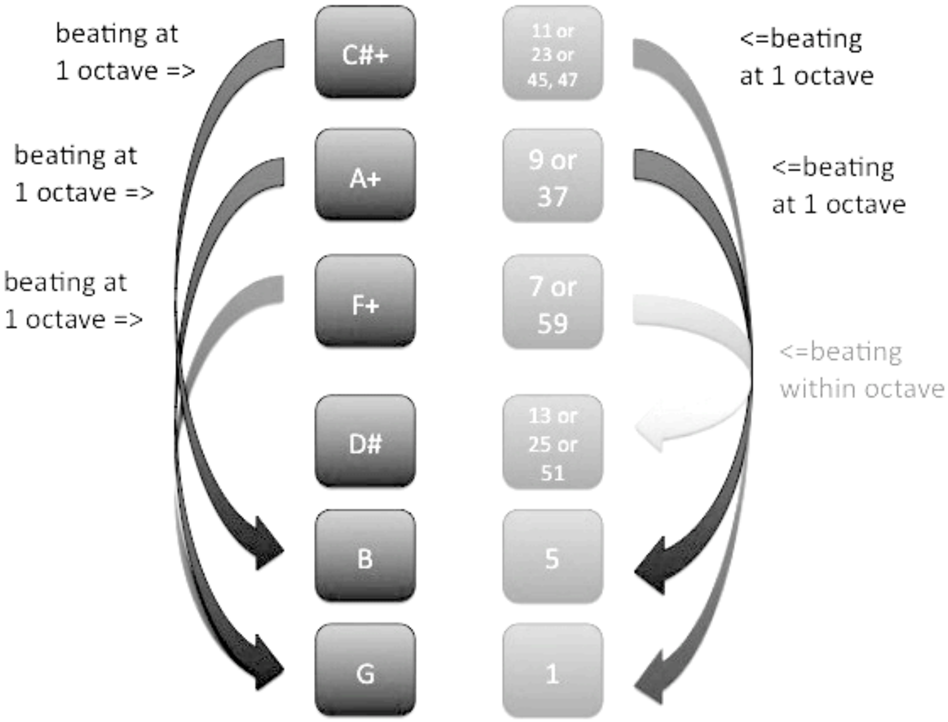


Figure 8(a): Representation of the first chord from the Largo *in Ives (1924)*

Intervals used are compared with harmonic series intervals, with indication of the potentail for resultant beating effects

The example above bears out some of Ives's previous comments regarding the perceptual effects of microtonal materials; specifically, that such clusters are 'not especially harsh' sound 'similar to the sounds one hears on putting the ear close to telegraph pole in a high wind' (Ives, 1925, p.117), i.e. make the harmonic series audible.

---

provide a recognisable approximation of the harmonic series (piano tones possess pitch) and, in any case, the equally-tempered intervals above only need to approximate harmonic frequencies to produce beating effects (whose genesis and broader perceptual implications will be discussed in detail in chapter five).

(It should be noted that this account describes augmented triads tuned in quartertone offsets, similar to the configuration of the chord in figure 8(a) and its companions.) Ives makes use of the shimmering harmonic beating effects engendered by these materials to evoke harmony as the product of what traditional Western music theories would consider the most dissonant of materials. Indeed, the second chord—figure 8(b), below––uses different voicings of extends these effects to higher harmonics (whilst reducing the beating of the lowest components).

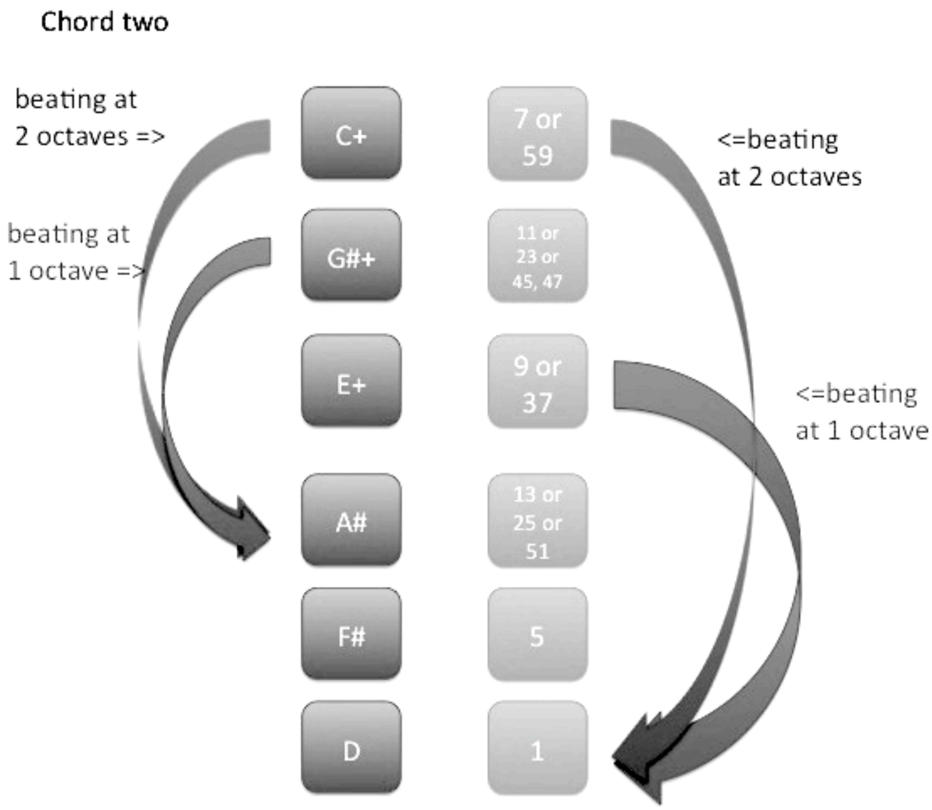


Figure 8(b): Representation of the second chord from the Largo in Ives (1924)

Intervals used are compared with harmonic series intervals, with indication of the potentail for resultant beating effects

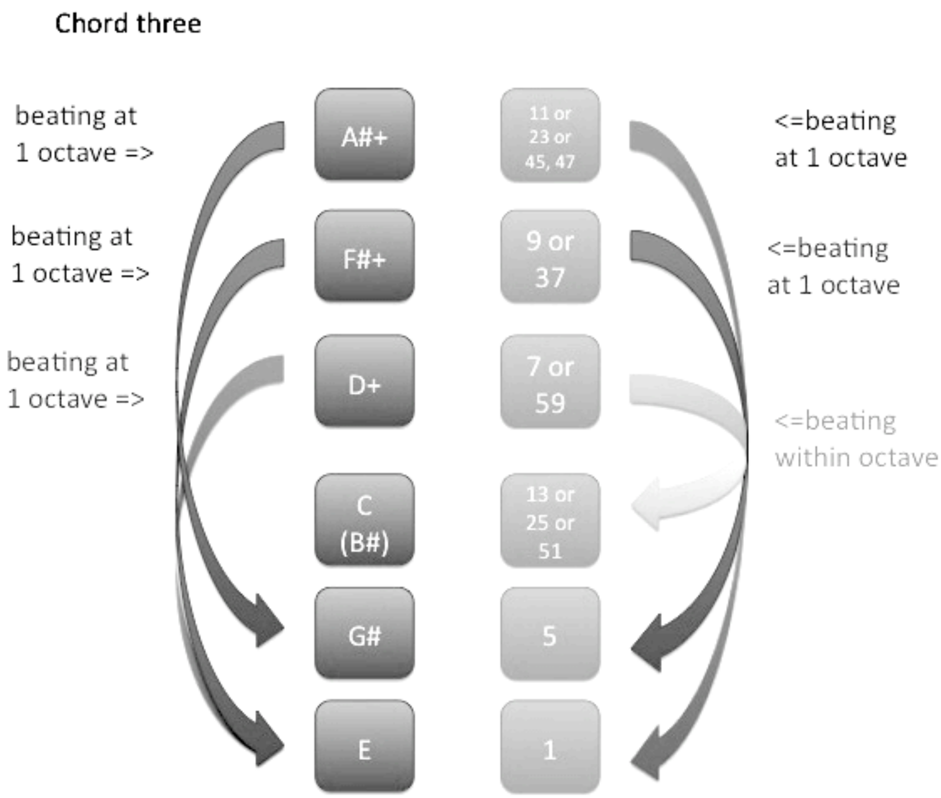


Figure 8(c): Representation of the third chord from the Largo *in Ives (1924)*

Intervals used are compared with harmonic series intervals, with indication of the potentail for resultant beating effects

Chord three—figure 8(c), above—can be seen to be based on a transposed version of the chord one voicing: only root note and register have been altered.

In addition to this type of usage, Ives also investigates the melodic properties of microtonal materials, which, similarly to the usage of Hába, frequently take the form of primarily 12TET melodies with quartertone offsets: cf. bars 4–6, 42 54–58 and from bar 60 to the close of the Largo, although the Allegro has a significantly greater degree of interplay between what are still discernible as discrete modules of quartertone–offset materials (see figure 9, below).

Figure 9: Melodic reduction of bars 51–52 from the Allegro of (Ives, 1924).

In summary, of the effects posited in the essay discussed previously (Ives, 1925), it is particularly notable that he clearly engages in his compositional practice with the following 'points' from the list above:

(3) Melodies with somewhat diatonic structures modified by finer degrees of pitch quantisation nonetheless still possess a significant degree of functional familiarity—effectively a corollary of his point 7 (above) in relation to chords

(6) The defamiliarising aspect of quartertone offsets (related to the tension between familiar 12TET and unfamiliar 24TET divisions) is exploited through alternating melodic materials with quartertone offset 12TET tunings

(8) Effects on timbral grouping and segregation (and point 5's awareness of the effects of relative amplitude of quartertone chords on the perception of dissonance—primarily related to changing spectral qualities of timbre with dynamics) through the use of Quartertones to accentuate harmonic beating effects

With these points in mind, Ives could be said to be an important progenitor of a perceptually-grounded theory and practice of microtonal composition, even if he did not compose extensively for these materials.

2.7 Hybrid Approaches: Compromises between Equal Temperament and Just Intonation via Nineteen–tone Equal Temperament (19TET) and beyond (Yasser and Fokker)

A number of early/mid–twentieth century theorists reprised a concern for intonation in the context of *hybrid* scale constructions which sought a compromise between two apparently opposing principles which had been a feature of scale construction prior to the twentieth century: just intonation/'pure' tuning and equal division of the octave. The first significant example of this approach is the 19TET (nineteen–tone equal temperament) scale advocated by Yasser's (1975/1932) *Theory of Evolving Tonality*. Mandelbaum (1961, p.246) notes that this type of approach had been described *but not advocated* prior to the twentieth century[43] and that Yasser's (1975/1932) exposition is the most substantial early contribution to its advocacy (Mandelbaum, 1961, p.299).
A key plank of Yasser's theory was that tonality was evolving to encompass a greater number of intervals (hence, there was a clear microtonal rationale for the espousal of this system) on the basis of the Fibonacci series (2, 5, 7, 12, 19, 31), hence the arrival at 19TET (Yasser 1932, cited in Mandelbaum 1961, p. 302). This tonal evolution process was seen as being facilitated by a process of deploying accidentals or 'auxiliaries'

---

[43] Although 19-tone divisions have been found in the some Renaissance instruments (Zarlino is credited with the first known example), no conclusive evidence is present that they were tuned in 19TET (Mandelbaum 1961, p.246-9). An early explict reference to 19TET by Robert Smith in 1759 concludes that it is unfit for use due to the discrepancy between the accurate sixths and innacurate thirds—Smith was of the view that all of the main consonances should enjoy an fairly equal degree of accuracy (Mandelbaum 1961, p. 252).

which later become codified as scale notes (Yasser 1932, cited in *ibid*., p.302), with 19TET providing extra auxiliaries for 12TET-based music to engage in a further process of growth and development.

In use, 19TET balances the opposing principles of equal temperament and just intonation tunings by increasing the number of equal divisions of an octave to the point at which relatively accurate renderings of certain key intervals (i.e. the consonances—fifths, thirds, sixths) are created which, nonetheless, enjoy the beneficial attribute of facilitating transposition to the full range of keys without these intervals undergoing variations in size (and hence, intonation). The impetus for this approach can be seen through the illustration of 12TET's significant deviation from the 'ideal' tunings of a chromatic 5–limit just intonation scale (figure 10, below, next page).

Interval	Cents	Interval name	12TET comparisons
0: 1/1	0	unison	
1: 16/15	112	minor 2nd	(12TET 100 cents, c. 11 cents deviation)
2: 9/8	204	major 2nd	(12TET 200 cents, c. 4 cents deviation)
3: 6/5	316	minor 3rd	(12TET 300 cents, c. 16 cents deviation)
4: 5/4	386	major 3rd	(12TET 400 cents, c. 14 cents deviation)
5: 4/3	498	perfect 4th	(12TET 500 cents, c. 2 cents deviation)
6: 64/45	610	tritone	(12TET 600 cents, c. 10 cents deviation)
7: 3/2	702	perfect 5th	(12TET 700 cents, c. 2 cents deviation)
8: 8/5	814	minor 6th	(12TET 800 cents, c. 14 cents deviation)
9: 5/3	884	major 6th	(12TET 900 cents, c. 16 cents deviation)
10: 16/9	996.	Pyth. Mi. 7th	(12TET 1000 cents, c. 4 cents deviation)
11: 15/8	1088	Just major 7th	(12TET 1100 cents, c. 12 cents deviation)
12: 2/1	1200	Octave	

Figure 10: 5–limit Just Intonation Chromatic scale along with 12TET scale for comparison; cent values calculated by Scala[44] *quantised to 1 cent*

As can be seen from the table above, 12TET suffers from its notoriously poor major and minor thirds and sixths, though fifths, fourths and even the minor seventh provide reasonable renderings of 5–limit JI intervals. However, given the central role which thirds enjoy in the context of delineating key or major/minor mode in the dominant Western common practice idiom of tonal harmony, this may be regarded as a significant

[44] Scala (Op de Coul, 1997–present) is a cross-platform application for exploring microtonal (and more general xenharmonic) tuning and temperaments; see also commentary in Op de Coul and Schiemer, (2007) and Op de Coul (n.d.) regarding its file format.

weakness of this tuning approach. Furthermore, in the context of simultaneous combinations (chords), a third which only loosely approximates an integer ratio will contribute significantly to a periodicity–based dissonance. 19TET offers a solution to this problem based on an improved rendering of most (though not all) just intervals in spite of being based on an equal division of the octave. To summarise the table (figure 11) below (next page), the 19TET intervals provide excellent renderings of minor thirds and major sixths alongside improved renderings (in comparison with 12TET) of major thirds and minor sixths, although the perfect fifth is quite poor[45] and sevenths and seconds are very poor at c. 15 cents out of tune.[46]

---

45 Partch, amongst others, criticised the 'absurd' situation of a perfect fifth (the second strongest consonance in Western musical practice) mistuned by approximately 7 cents (Partch, 1974, p.333).

46 However, Yasser's conception of consonance and dissonance in this system is based upon scalar structure and note position rather than simplicity of integer ratios, with the principle of diatonicity (inequality of step size) held to be an essential attribute of scale structure for expressive musical purposes (Yasser, 1932, p.56, cited in Madelbaum 1961, p.300). He delineates a differene between functional scale (the musical structure which embodies consonant relationships and the most established musical practice) and the avant garde of the auxilliary scale (which provides the extra materials for the extension of the functional scale to the next stage of its evolution). Dissonance is held to be the property of consecutive scale steps in the functional scale, whereas consonance is the property of leaving gaps and utilising alternate steps.

Interval	Cents	Interval Name	Deviation from 5-limit JI	Other close ratio[47]
0	0.000	unison	none	1/1
1	63			28/27
2	126	minor second	poor - circa 15 cents	14/13 (69/64)
3	189	major second	poor - circa 15 cents	29/26 (71/64)
4	253			22/19 (37/32)
5	316	minor third	very good - less than 1 cent	6/5
6	379	major third	fair - circa 7 cents	36/29 (5/4)
7	442			22/17 (83/64)
8	505	perfect fourth	fair - circa 7 cents	4/3 (43/32)
9	568			25/18 (89/64)
10	632			36/25 (23/16)
11	695	perfect fifth	fair - circa 7 cents	3/2
12	758			45/29 (99/64)
13	821	minor sixth	fair - circa 8 cents	45/28 (103/64)
14	884	major sixth	very good - less than 1 cent	5/3 (107/64)
15	947			19/11 (111/64)
16	1011	Pyth. Mi. 7th	poor - circa 15 cents	52/29 (115/64)
17	1074	Just major 7th	poor - circa 15 cents	13/7 (119/64)
18	1137			27/14 (123/64)
19	1200	octave	none	2/1

Figure 11: 19TET scale in comparison with 5–limit just intervals; cent values and other (non–5–limit) close ratios via Farey approximations[48] *of cent calculated by Scala*

---

47 Relatively low-integer ratios and harmonic series ratios (bracketed) within first 128 harmonics; see also footnote 39.

48 Scala's *Farey* command—see Op de Coul (1997)—allows for the replacement of each pitch in a given scale with a fraction/integer ratio which has a denominator equal to or smaller than a given order and within a given prime limit. For the present purposes, the default order value of 36 was used alongside a factor of 29 for the prime limit for factors embodied within the numerators and demoninators of each fraction (see discussion of extended just intonation in chapter three for further discussion of this issue). This type of approximation has its origin in the Farey series, which was named after John Farey (1766–1826), British geologist of mathematical and musical interests, who also investigated methods of tuning for equal temperament (Benson, 2006, p.191). The Farey sequence is the set of rational numbers between 0 and 1, given in their order as real numbers, with the entire set being contained by the order value (Huxley, 1996, p.8).

In addition, in terms of its microtonal potential, 19TET obviously offers a somewhat finer degree of pitch quantisation than 12TET, though it possesses a coarser degree of 24TET (and does not offer the easy nomenclature of categorisation which a simple subdivision of standard chromatic intervals would have). However, many of the smaller intervals which 19TET adds do not align closely with intervals of small number ratios which have been deployed by microtonal composers who are exponents of just intonation, such as those from the earlier intervals of the harmonic series[49] or extended just intonation systems (ratios based on integer multiples with prime factors greater than five), such as those which use seven as the highest prime factor.[50] Nonetheless, enharmonic distinctions between augmented fourth and diminished fifth are relatively well served and a loose quartertone approximation is to be found in the first interval. Mandelbaum (1961, pp.336–6), noting the issues with the rendering of the fifth and harmonic seventh, concedes that 19TET remains, fundamentally, a compromise system in the mould of 12TET, which possesses the virtue of reinstating a (clearer) connection with 'the natural harmonic system' whilst also benefiting from the modulatory convenience of a temperament. Based on the attributes discussed, 19TET can be regarded as possessing greater potential in its rendering of standard 5–limit chromatic intervals (including enharmonic distinctions) than in providing a significantly enhanced microtonal vocabulary. It is a microtonal tuning system which is of more potential utility in accurate tuning of established chromatic intervals than the significant expansion of the interval vocabulary.

Another system of equal temperament which seeks a compromise between the convenience of equal subdivision and the intonational integrity of just intonation is thirty–one–tone equal temperament (31TET).[51] 31TET obviously provides for finer

[49] A few higher harmonics are present in reasonable numbers and density, e.g. 99–123 with relatively few gaps.

[50] Extended just intonation will be discussed further in chapters three and four; the discussion of 31TET, below, will also provide some preliminary details.

[51] The selection of 31TET after 19TET is consistent with Yasser's espousal (discussed above) of the

pitch quantisation (at 38.71 cents) than 19TET and 24TET and, in addition, provides a partial improvement upon the extremely problematic fifths of 19TET.[52] Indeed, one significant benefit of this scale is that it provides a reasonable approximation of twelve-division quarter comma meantone tuning within its structure (Benson, 2006, pp.219–20). The origins of Western investigations into 31TET can be traced to Vincentino (1555, cited in *ibid*.) and Huygens (1691, cited in *ibid*.), but the twentieth century exploration of this scale was revived by Adrian Fokker, a Dutch physicist and composer-theorist who advocated (Fokker, 1955) this tuning as the solution to increased melodic nuance and improved harmonic sonorities.[53] Fokker (*ibid*.) advocated reprising the *nouveau cycle harmonique* of Huygens, which attempted to preserve the distinction between major and minor semitones; the difference between these semitones was taken as an approximation of the unit for the equal division of the octave. For just intonation, this interval, the *diesis*[54] can also be found by the difference between an octave and three just major thirds, which is 125/128. This ratio gives a value of approximately 41 cents. (However, the 31TET division is closer to the septimal diesis (45/44) which is approximately 38.9 cents, with an accurate value for 31TET divisions being 38.7 cents). An 'intuitive' approximation, provided by Fokker (1955) is thus 1/5 of a tone (or 40 cents).

Fokker's advocacy of this approach eventually led to the construction of at 31TET organ whose keyboard interface (see figure 12, below, next page) follows the enharmonic division/'accretion principle' (Keislar, 1987) format of earlier microtonal

---

Fibonacci sequence as describing evolving tonality/scale construction. See Mandelbaum (1961, pp.299–312) for more detailed commentary on Yasser's theories and their implications.

52 Indeed, these fifths were so problematic that Yasser (cited in Madelbaum, 1961, p.306) suggested that they be eliminated from the set of consonances in 19TET.

53 His advocacy eventually led to the construction of at 31TET organ whose keyboard interface which follows the enharmonic division/'accretion principle' (Keislar, 1987) format of earlier microtonal keyboard interfaces with a significant number of vertical splits to the keyboard in various octave registers. Keislar notes that an early instance of extensive vertical enharmonic divisions can be found in the designs of Bosanquet in the late 19th century (Keislar, 1987, p.21).

54 See Monzo's (2005) discussion of the varied use of this term.

keyboard interfaces with a significant number of vertical splits to the keyboard in various octave registers.[55]

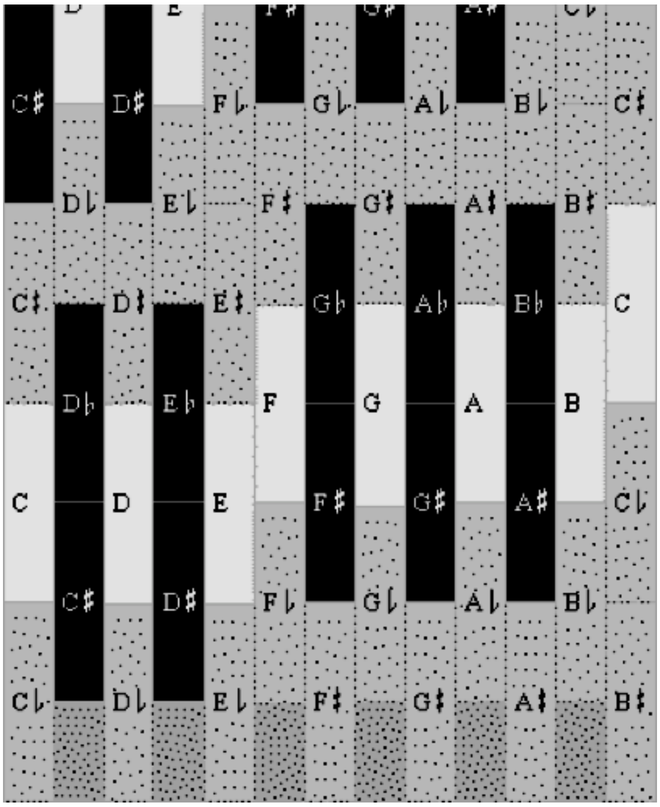


Figure 12: Fokker's 1950 31TET organ interface (Huygens-Fokker Foundation, n.d.)

see Fokker (1955) for further detail regarding this keyboard design

A particular focus in Fokker's early discussion of 31TET tuning was the harmonic seventh (7/4), which 19TET cannot reproduce accurately. As a by-product of this consideration and in order to conceptualise the connections between prototypical intervals based on the primes 2, 3, 5 and 7 (the 'newly admitted' consonance[56]), Fokker (1955; 1969) drew a lattice diagram (see figure 13, next page) to represent the

---

55 Keislar notes that an early instance of extensive vertical enharmonic divisions can be found in the designs of Bosanquet in the late 19th century (Keislar, 1987, p.21).

56 As Fokker (1955), puts it, '[i]f we now recognise the harmonic seventh as a legitimate concord, there is evidently good reason to extend the [two-dimensional] representation [of harmonic relationships] to a three-dimensional one.'

dimensionality of these primes in musical relationships, following those of Euler (1739), who had previously conceptualised fifths and thirds as arrayed on horizontal and vertical axes.[57] Fokker's innovation was the addition of the extra dimension to represent the 7-based intervals and such lattice diagrams are sometimes termed *Euler–Fokker genera* within the field of microtonal music theory: see Rasch (2000), Op de Coul (1997–present) and Burt (2007).

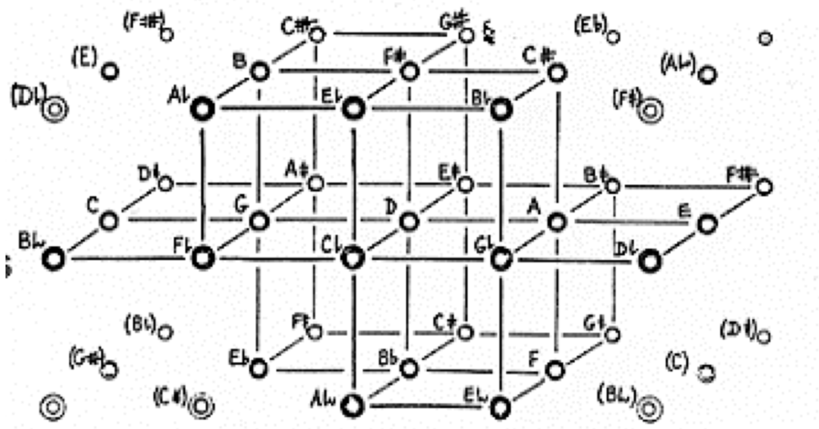


Figure 13: Three–dimensional lattice diagram based on Fokker (1955)/Huygens-Fokker Foundation (n.d.)

3s are horizontal (fifths); 5s are vertical (thirds); 7s are diagonal (harmonic sevenths/septimal major seconds); 2s are not represented based on octave equivalence

Fokker (1969) describes in detail the use of three–dimensional matrices to provide a vector representation of the intervals in his lattices (and advocates the use of this notation as a simplified alternative to the addition of chains of accidentals.[58] Thus, we

[57] The separate influence of Euler's lattice diagrams on the work of Harry Partch and Ben Johnston will be discussed in chapter three.

[58] However, this type of notation, whilst allowing for a clear sense of the modulatory movements which might produce a given interval, arguably provide less immediate insight into the relative size of a

have the following based on visualising relationships of major thirds (5/4), fifths (3/2) and sevenths (7/4) to a central note (see figure 14, below):

```
                                        -1  1 -1   0  1 -1   1  1 -1
                                            C#        G#        D#
                                        -1  0 -1   0  0 -1   1  0 -1
                                            A         E         B
                                        -1 -1 -1   0 -1 -1   1 -1 -1
                                            F         C         G

                    -1  1  0   0  1  0   1  1  0
                        B         F#        C#
                    -1  0  0   0  0  0   1  0  0
                        G         D         A
                    -1 -1  0   0 -1  0   1 -1  0
                        Eb        Bb        F

-1  1  1   0  1  1   1  1  1
    A         E         B
-1  0  1   0  0  1   1  0  1
    F         C         G
-1 -1  1   0 -1  1   1 -1  1
    Db        Ab        Eb
```

Figure 14: Three-dimensional matrix representation after Fokker (1969) for intervals/nodes based on 3, 5 and 7-limit frequency ratios

Each co-ordinate for a node in the lattice is given by three numerals for vectors (in order) for x, y and z (3, 5 and 7) modulations. D is used for the central pitch by Fokker's convention. See also figure N for a related lattice diagram from Fokker (1955)/Huygens-Fokker Foundation (n.f.) which describes the formal/functional connections implied by 31TET tuning.

In this adaptation of Fokker's diagram, to provide added clarity I have added approximate indications of note/interval provided through standard letter notation (no microtonal deviations introduced through tuning are indicated). The *periodicity* within the name *periodicity block* refers to the definition of closure within harmonic space whereby certain minor deviations from established interval identities are treated as

given interval than either standard note names with accidentals or (if accuracy is important) standard ratio-based notation.

unison vectors (as is the case where microtonal tuning deviations are excised/considered to be so close to unison as to be negligible) and thus create a bounded space or period within an otherwise infinite and undivided harmonic space (Fokker, 1969, sections 2 and 4). They therefore allow Fokker to represent the extent of the harmonic space encompassed within a particular scale design which rationalises according to temperament (or usage convention). As such, they provide an encapsulation of a scale's extent (in terms of number of octave divisions) and formal/functional attributes (by way of the dimensionality and the approximation/limiting via the unison vectors).

To explain the direct application of this representation, Fokker's (1969) three-dimensional periodicity block for 12TET (which assumes that the function of the harmonic seventh is to be included) can be described using the following vector notation **(vectors refer to x, y, z or 3, 5, 7 dimensions):**

$$12 = \begin{vmatrix} 4 & 2 & 0 \\ 4 & -3 & 2 \\ 2 & 2 & -1 \end{vmatrix}$$

The vectors themselves which describe the unison vectors in sum are given by the three figures in each row of the matrix. Fokker (1969, section 2), gives the following example for rationalising sevenths within a three–dimensional 3, 5, 7 space:

(2, 2, -1)[59]+(0, 0, 1)[60]=(2, 2, 0)[61]

This indicates the degree of approximation which is taking place: the 'removal' of the seven-based dimension (i.e. reducing down to a two–dimensional functional representation) means that (2, 2, -1) is assumed to *effectively* equal (2, 2, 0). Evaluating the expression as tuning ratios, we have:

---

59 Modulating up by two fifths, followed by two major thids and down by a minor seventh, reaching *Cb* (assuming, by Fokker's convention, that the starting points is *D).*

60 Modulating up by a minor seventh, reaching *C* (through a 7/4 ratio).

61 Modulating up by two fifths, followed by two major thirds, reaching C (through a 2025/2048 ratio).

(3/2)^2 * (5/4)^2 * (7/4)^-1 = 9/4 * 25/16 * 4/7 = 225/112 = 225/224 (within one octave, based on octave equivalence).

Since we have this equivalence:

Cb [the seventh we want to remove] *** 225/224** [our seventh's approximation of this seventh] **≈ *B# or* 225/224 * 7/4 ≈ *B#* or 225/224 * 7/4 ≈ 225/64**

To evaluate the matrix above for its *determinant* (to find its area, and hence, number of notes, so that we can check that the representation of this periodicity block is correct), after Erlich (1999, part 3), we have:

(4*-3*-1)+(2*2*2)+(0*4*2)-(0*-3*2)-(4*2*2)-(2*4*-1)

=(12)+(8)+(0)-(0)-(16)-(-8)=12

Thus, this matrix describes certain unison vector characteristics which produce a twelve-note scale.

Fokker (1969, sections 3, 4) thus uses these methods to demonstrate the efficacy of 31TET in encompassing a range of functional tuning relationships including the seventh (within the limits of a diesis as unison vector), with examples discussed relating to a number of unison vectors (variants on commas) similar to the one above. Based on the correspondence between these unison vector sizes and the diesis, the latter is taken as the smallest division need to provide reasonable approximations of enharmonic distinctions whilst constraining the overall number of divisions in the scale:

> The shifts produced by these substitutions amount to 2/5 comma at most[62] […] As far as these figures [for substitution based on unison vectors for sevenths] go, a fair approximation is shown to take five *diëses* in a tone, two *diëses* in a flat or in a sharp, and two commas in a *diësis*. (*ibid*., section 3)

Based on the constraining of harmonic space based on unison vectors encompassing less than a diesis, a scale can be constructed which maintains the general integrity of

---

[62] Which 225/224 does, at 7.71 cents, or 1/5 of a diesis (with 2 dieses in a comma).

enharmonic tuning distinctions and the seven-based dimension whilst also being structured around equal step sizes.

Fokker's periodicity block notation for 31TET enumerates the limits beyond which the discrete scale–space repeats.

```
         | 4   -1    0   |
31 =     | 2    2   -1   |
         | 1    0    3   |
```

Evaluating the first row: (3/2)^4 * (5/4)^-1 = 81/16 * (4/5) = 81/20 = 81/80 (within one octave)

> Thus, modulations up by four fifths plus one down by a major third deviates from the root note by a syntonic comma (81/80)

Evaluating the second row: (3/2)^2 * (5/4)^2 * (7/4)^-1= 9/8 * 25/16 *4/7 = 225/224

Evaluating the third row: (3/2)^1 * (7/4)^3 = 3/2 * 343/64 = 1029/128 = 1029/1024 (within one octave)

Fokker (1969) provides two other matrices which describe similar limiting cases whereby a close approximation of the unison/root occurs, all three are printed below:

```
     | 4   -1    0   |      |4  -1    0 |     |  1   5    1 |
31 = | 2    2   -1   |   =  |0   3    5 |  =  | -1  -2   -4 |
     | 1    0    3   |      |1   0    3 |     |  1  -3   -2 |
```

The entire resulting scale can be seen in figure 15 (below, page after next), which also includes comparisons with harmonic series intervals and small-number ratios with relatively low dimensionality (via approximations of 7-based and 29-based[63] interval

[63] 29 is taken as an aribtrary relatively high prime factor for interval ratios, demonstrating that beyond 31TET's reasonable performance in relation to many 7-limit intervals is an even closer approximations of integer ratios based on somewhat higher primes. Formal models and compositional usage of intervals based on higher primes is further discussed in relation to the work of Johnston in

ratios). As can be seen, this type of scale is much more successful than 19TET in approximating a wide variety of microtonal intervals which are connected to a range of organisational approaches to microtonal music based on 'pure' tuning or integer ratios, even with a fifth, minor third (6/5) and major sixth (5/3) which are out by over 5 cents.[64] A wide range of harmonic 'variants' on standard intervals with relatively sparse gaps between them would provide some degree of satisfaction to a proponent of spectral music who was concerned with relatively accurate intonation of smaller/higher harmonic series intervals (up to the 117th and 125th harmonic). This is in addition to Fokker's immediate aim of incorporating an accurate rendering of intervals based on the harmonic seventh in addition to preserving enharmonic distinctions which are all assumed to be perceptually and functionally significant.

---

chapter three.

64 Although the fifth is an improvement on 19TET.

31TET	Cent values	Closest… harmonic[65]	…7-limit[66]	…29-limit[67]
0	0 cents	1/1	1/1	1/1
1	40	n/a	*36/35*	*36/35*
2	77	67/64	*25/24*	23/22
3	116	n/a	15/14	15/14
4	155	35/32	35/32	35/32
5	194	*9/8*	28/25	19/17
6	232	73/64	8/7	8/7
7	271	75/64	7/6	7/6
8	310	*19/16*	*6/5*	*6/5*
9	348	39/32	n/a	11/9
10	*387*	5/4	5/4	5/4
11	426	41/32	32/25	23/18
12	465	*21/16*	21/16	17/13
13	503	*85/64*	4/3	4/3
14	542	*11/8*	48/35	26/19
15	581	*45/32*	7/5	7/5
16	619	*91/64*	10/7	10/7
17	658	*47/32*	35/24	19/13
18	697	*3/2*	*3/2*	*3/2*
19	735	49/32	49/32	26/17
20	774	25/16	25/16	36/23
21	813	*51/32*	8/5	8/5
22	852	*105/64*	49/30	18/11
23	890	107/64	5/3	57/34
24	929	*109/64*	12/7	12/7
25	968	7/4	7/4	7/4
26	1006	*57/32*	25/14	34/19
27	1045	117/64	64/35	64/35
28	1084	15/8	28/15	28/15
29	1123	*61/32*	*48/25*	44/23
30	1161	125/64	49/25	45/23
31	1200	2/1	2/1	2/1

Figure 15: cent values and interval approximations for 31TET; cent values and approximations calculated by Scala (rounded to 1 cent); interval renderings which are more approximate are indicated in italicised red (see individual footnotes)

---

[65] Within first 128 intervals of the harmonic series; this is chosen as a practical maximum based on the usage in Branca's (1983) Symphony No. 3 (Gloria), which is subtitled *Music for the first 128 intervals of the Harmonic Series,* which is one of the most extensive explorations of higher harmonic intervals in contemporary music. All harmonic values are normalised to within an octave and provided as ratios; harmonics approximated to within 5 cents (standard script) or 10 cents (italics).

[66] The 7-limit approximation (via Scala's Farey approximation) illustrates intervals which have prime factors of 7 which are close to 31TET intervals. Those within 10 cents of 31TET originals are denoted with italics, with intervals within 5 cents of 31TET appearing in normal type.

[67] The 29-limit approximation (via Scala's Farey approximation) denotes intervals within 10 cents of 31TET originals in italics, with intervals within 5 cents of 31TET in normal type; most of these intervals are in fact within c. 1 cent.

31TET is therefore an approach to equal temperament which benefits from the crucial innovation of being expressly designed with the aim of extending harmonic practice through the careful rendering of microtonal variations whilst maintaining the convenient homogeneity of its basic interval size. For the practical implementation of extended microtonal practice in fixed–tuning instruments (such as keyed or fretted instruments) this approach has great potential utility for the exploratory microtonalist who is interested in 'pure' tunings but who is not overly concerned with (or whose form of practice is not affected by) the occasional approximation of these tunings. In addition, Fokker's concept of unison vectors (and representation of scales via periodicity blocks) provides an early attempt to engage with the problematic proliferation of microtonal materials encountered when rigidly adhering to modulation by a set integer–ratio–based interval size and the somewhat related issue of how to conceptualise a spatial–functional representation of microtonal intervals.

2.8 Hybrid Approaches Beyond the Octave Delimiter: the Bohlen–Pierce Scale

A scale structure which seeks to balance the convenience of equal division with the production of close approximations of integer ratios does not necessarily need to be based upon the division of the octave. German communications engineer Heinz Bohlen (1978) developed a scale of simple integer ratios based on a thirteen–fold division of an octave plus fifth (3/1). This scale was independently discovered by John Pierce (Mathews and Pierce, 1980; Mathews, Roberts and Pierce, 1984), who coined the term *tritave* for the 3/1 interval and discussed theoretical and practical aspects of this scale such, including the role of ear training in recognising more complex pitch relationships within this system (Mathews, Pierce, Reeves and Roberts 1988). This tuning approach is also described in succinct terms in Pierce (2001, p.183). Whilst not expressly microtonal (based on the definition in the introduction), this scale structure does embody an expressly different scale structure from that of other scales in Western music (even if it does embody the dual-size step/half-step diatonicism and chromaticism of Western scale structures) and so is not simply an alternate tuning variation of standard interval specifications.

A diatonic version of the Bohlen–Pierce scale steps can be generated as follows: this discussion follows Loy (2006, pp. 87-89).

1: Define root of scale and create triad with ratios 3:5:7. (The tritave pseudo-octave delimiter corresponds to 3/1.) The result is a triad with ratios 1/1, 5/3 and 7/3 (with a pseudo-octave or tritave at 3/1.)
2: Another triad is defined by starting with 5/3 as the root: 5/3, 7/3, 9/3 (3/1) triad or 5:7:9.
3: Transpose 3:5:7 triad such that top pitch is 9/3 (3/1). To find the root pitch, 7/3 is subtracted from the tritave (3/1). Therefore 3/1 divided by 7/3 = 9/7.
4: Find middle pitch by adding 5/3 interval to root (as this is the same triad 'shape'): 9/7 * 5/3 = 45/21 = 15/7.
5: Take 5:7:9 triad and place root on first degree—i.e. subtract 5/3 (its original starting point) from each interval, resulting in 5/5, 7/5 and 9/5.
The resulting scale is:
1/1, 9/7, 7/5, 5/3, 9/5, 15/17, 7/3, 3/1
As the highest prime is 7, this is a 7–limit scale. It finds a point of contact with a just diatonic scale at 5/3 (minor 6th).

A chromatic version of the scale can then be constructed by replacing the larger (diatonic) intervals/scale steps with a combination of smaller ones. An intermediate step is the replacement of these larger steps with a combination of small and medium–sized steps, for which are substituted a number of the smaller steps sizes (in an analogous manner to the whole–tone and semitone divisions within 12TET). Again, following Loy (2006, pp. 89-91):

1: Calculate step sizes for diatonic scale:
Step 1=9/7 divided by 1/1 = 9/7
Step 2=7/5 divided by 9/7 = 49/45
Step 3=5/3 divided by 7/5 = 25/21
Step 4=9/5 divided by 5/3 = 27/25
Step 5=15/7 divided by 9/5 = 25/21
Step 6=7/3 divided by 15/7 = 49/45
Step 7=3/1 divided by 7/3 = 9/7

2: We now have a number of unequal step sizes. Is substitution possible? In fact, two of the smaller intermediate intervals can be added together to provide 9/7, i.e. 27/25 * 25/21 = 9/7.
Larger (9/7) steps can therefore be replaced with a combination of medium (25/21) and small (27/25) intervals. There is also a small step of a different size (49/45).

3: Neither small step (pseudo–semitone) divides the medium step into two equal parts—subtracting the two different pseudo-semitones from the medium step produces a variety of pseudo–semitones, resulting in variations on this scale step of 27/25, 49/45, 375/343 and 625/567 (from small to larger).

4: Substitution of various intervals proceeds to divide the scale using these unequal pseudo–semitones to further divide the medium–sized steps already obtained on the basis of small pseudo–semitone plus larger pseudo–semitone for each 9/7 step.
This results in a scale of:
1/1, 27/25, 25/21, 9/7, 7/5, 75/49, 5/3, 9/5, 49/25, 15/7, 7/3, 63/25, 25/9 and 3/1.

Again, this scale has as its point of contact with an octave 5–limit JI scale the 5/3 (major sixth).

An equal–tempered version of the Bohlen–Pierce scale (see figure 16, next page) is often held to be quite close in tuning to the intervals of its just counterpart—cf. Loy (*ibid*., pp.91–2). However, whilst some intervals are undoubtedly very close, frequent deviations of 10–15 cents (along with one 20 cents deviation) bear comparison with 12TET deviations[68] which are equivalent in size, as seen in figure 10 from the previous section. Nonetheless, the overall scale structure is close to ratios of odd harmonics, as Mathews and Pierce (1988, cited in Sethares, 2004, p.111) have noted. As Sethares (*ibid.)* further clarifies, the Bohlen-Pierce *tritave* therefore adds no new harmonic partials to a pre–existing spectrum, thus making it an analogue of the octave's role in producing largely coincident intervals for harmonic spectra.

---

[68] And, indeed, 19TET deviations from 5-limit just intonation.

Equal-tempered BP scale (cents)	**Just BP scale and assessment (ratio and cents)**
0: 0	*1/1 – identical*
1: 144	27/25 or 133 cents
2: 288	25/21 or 302 cents
3: 431	9/7 or *435 cents – good, less than 5 cents deviation*
4: 616	7/5 or 583 cents
5: 756	75/49 or 737 cents
6: 897	5/3 or 884 cents
7: 1038	9/5 or 1018 cents
8: 1183	49/25 or 1165 cents
9: 1327	15/7 *or 1319 cents – fair, c. 7 cents deviation*
10: 1471	*7/3* or 1467 cents– *good c. 4 cents deviation*
11: 1614	63/25 or 1600 cents
12: 1758	25/9 or 1769 cents
13: 1902	*3/1 – identical*

Figure 16: Equal-temperament version of the Bohlen-Pierce Scale compared with just version, calculations by Scala[69]

Particularly close intervals are indicated in italics

Compositionally, the Bohlen–Pierce scale has been investigated in pieces by, amongst others,[70] Richard Boulanger, whose piece *I Know of no Geometry* (1988/9) extensively explores the smaller steps of the new scale in a manner which is redolent of the complex and evolving 'drone-cloud' harmonic–series exploration of composers such as James Tenney's *Spectral CANON for COLON Nancarrow* (Tenney, 1974) and the harmonic series works of Glenn Branca. Another piece by Boulanger, *Solemn Song for Evening* (1990), explores the more expressive qualities of disjunct/diatonic-style presentations of larger intervals). This type of presentation tallies with the views of Mathews and Pierce

[69] Approximated to three decimal places.
[70] Jon Appleton's 1987 *Eros Ex Machina* is another prominent example which is included in Mathews and Pierce (1989).

(1989) whose investigations have suggested that perceptions of Bohlen–Pierce intervals as consonant are present in a wide variety of configurations, with their conclusion being that training and exposure could lead to a recognition of the scale's diatonic structure and its resultant compositional viability in this domain. However, a focus on such a diatonic presentation with relatively large intervals can be regarded as antithetical to the microtonal (i.e. small subdivision as opposed to a xenharmonic *alternative tuning*) ethos. Based on the definition advanced at the start of this thesis, such uses of Bohlen–Pierce demonstrate the scale's xenharmonic as opposed to specifically microtonal practice. Nonetheless, the Bohlen–Pierce scale offers an example of how a non-standard (i.e. xenharmonic) scale structure can be structured based on perceptual organisational principles (relative minimisation of sensory dissonance through a greater tendency for the coincidence of partials in odd-harmonic spectra) alongside the ease of structural recognition for its diatonic structure. As such, the scale provides an example of how alternative formal scale structures might be constructed to take account of the 'grounding' effect of perceptual organisation.[71]

[71] As Sethares (2004, p111) notes, Mathews and Pierce found discrepancies between 'naïve' and 'trained' listeners, non-musicians tending to prioritise sensory judgements and musicians tending to note the unusual interval sizes/positions, judging chords as more dissonant than might be expected by such a model. Nonetheless (*ibid.*, p.112) Sethares notes that the major and minor analogues proposed by Mathews and Pierce will produce relatively minimal sensory dissonance (if articulated by odd-harmonic spectra) at the diatonic intervals steps 3, 4 6, 7, 10 and 13.

2.9 Conclusion: Assessment of Early Equal Temperament Microtonality and Hybrid Approaches

As can be seen from the composers discussed above, the earliest developments in the use of microtonality were conceptualised on the basis of the subdivision of the smallest interval then in common usage: the 12TET semitone. This is in contrast with some later approaches which revisited the wider question of the division of the octave into intervals derived from integer ratios (hence, a concern for relative periodicity of the intervals). Although most of these early equal temperament microtonal composers (or composer–theorists) cited smaller harmonic series intervals as inspiration and/or justification in the deployment of these new intervals, they did not, in general, prioritise an adherence to harmonic series tunings with a significant degree of precision, nor engage with the unequal structure inherent within the series. Rather, the focus was primarily on the functional implications of the deployment of these new materials, still somewhat grounded in earlier theories and practice related to functional harmony and the contemporary elaboration of this through equally–tempered chromaticism. (However, the equal subdivision of the octave which prevailed in early twentieth-century investigations of microtonality is not necessarily incompatible with a concern for relative accuracy of tuning, particularly if not limited to the duple subdivision of established 12TET divisions, as the work of Yasser and Fokker showed, in addition to the later non–octave work of Bohlen, Pierce and Mathews.)

Of the early microtonalists, Wyschnegradsky extended the structural scope a little further through his experimentation with the new formal possibilities in microtonal diatonic scale construction and modulation to new keys at microtonal offsets. However, in common with Hába, he developed a conception of microtonal compositional structuring which was very much based on the approach of functional harmony, highlighting the importance of voice–leading structures and codified chord progressions with microtonal offsets to accentuate the tension–and–release axis of the functional approach. For the beginnings of microtonal exploration, a clearly beneficial by-product of the conceptual basis of new scale materials as being based on a simple duple subdivision of the standard semitone (which was already easily conceptualised as a subdivision of the standard whole-tone) is that it provided an easily comprehensible model for microtonal extension of Western musical practices. Indeed, such was the conceptual compatibility with chromaticism that it is perhaps somewhat surprising that quartertone microtonalism was not utilised more widely by early twentieth century composers. In addition, the conception and deployment of these microtonal materials as effectively extending chromatic harmony undoubtedly reinforced a certain degree of syntactical familiarity for listeners familiar with extended chromatic harmony who were exposed to the new materials.

However, some early twentieth–century approaches and conceptions were more clearly focussed upon the distinctiveness of microtonal materials. Carrillo engaged with the question of how to categorise these materials, concluding (with a 'strong' microtonal position) that new tunings of intervals, no matter how minor their difference from pre–existing renderings, produced interval categories which were essentially new, necessitating new functional implications. Whilst his position in this regard could be viewed as extreme (and whilst some of his related theorising is not judged to be entirely consistent in the present analysis), his writings are significant as examples of direct engagement with this important issue.

However, many of the more formally–based theoretical approaches of these early composer–theorists did not fully take into account the perceptual novelty of these materials and the resultant implication for musical structuring. The comparatively short essay by Ives, coupled with his small set of microtonal studies (the *Three Quarter–tone Pieces*) is arguably the early theoretical development which would possess the most lasting significance in this regard. Ives approached his quartertone materials with a predisposition towards novel sonorities and thus made pertinent observations regarding the perceptual implications of these new materials. His theorising in this regard could be seen as prefiguring the concerns and interests of a diverse range of subsequent microtonal composers (and, indeed, the central topic of the present thesis).

2.10 Chapter Summary

This chapter has contextualised the strand of microtonalism which is based on the ‘subdivision impulse’. In doing so, it has produced an integrated survey of early subdivision–based microtonality which has investigated the various claims for precedence and significance amongst the early 20th century microtonal pioneers. It has discussed the origin and implications of the ‘subdivision impulse’, alongside accounts of the syntactical implications of such structures and their potential integration with existing theories of functional harmony which were advanced by Hába and Wyschnegradsky in particular. It has also investigated the manner in which *hybrid* tempered scales (19TET, 31TET and Bohlen–Pierce) can balance the ‘subdivision impulse’ with the ‘natural intervals/pure tuning impulse’ in some musical contexts. Of more general significance, Carrillo's theorising is seen as raising some important questions regarding the (basic) perceptual and (more sophisticated) cognitive delineation of microtonal materials which prefigure the central topic of the present thesis. Finally, the significance of the astute practice–led insights of Charles Ives has been asserted with respect to his balanced engagement with perceptual and syntactical factors in microtonal music.

Chapter 3: Just Intonation Microtonality I: Harry Partch, Ben Johnston and Geometric Formal Models of Just Intonation

This chapter will discuss the theories and practices of early just intonation microtonalists Harry Partch and Ben Johnson. It will examine their modelling of just–intonation–based microtonality via spatial/geometrical descriptions alongside more perceptually–grounded conceptions of consonance/dissonance and functionally–based tonal relationships. In doing so, it will examine the degree to which their perspectives are consistent with those found within the field of psychology, assessing these contributions as potential components of a generalised theory of perceptually–grounded microtonality.

3.1 Progenitors of American Just Intonation Microtonality

This chapter will examine the theory and practice of two of the earliest exemplars of just–intonation–based microtonality in the USA, Harry Partch (1901–1974) and Ben Johnston (born 1926). Both composers have engaged with the theoretical implications of their new musical materials to a significant degree, informed by detailed reflections on their own compositional experience alongside attempts to engage with early research into auditory perception. Although their theorising undoubtedly provides only partial accounts of perceptual and cognitive issues in microtonality, the work of both practitioner–theorists nonetheless contains prescient insights into some of the structural and perceptual implications regarding the use of such materials. As such, they are worthy of detailed treatment both as historical progenitors and for their prototypical (and influential) microtonal theories.

The work of Partch and Johnston has many aspects in common beyond the obvious connection of microtonal just intonation. It should also be noted that the work of Johnston built upon foundations laid by Partch, in spite of their many differences in creative philosophy and media (with Partch presenting microtonal materials through his self-designed instruments and Johnston preferring to work for more standard Western instruments). However, the most significant connection between the work of these two seminal figures is the manner in which they conceptualised relationships between microtonal intervals; specifically, the development of graphic spatial representations of just intonation pitch materials. As such, this chapter will examine each composer's work in turn, with Johnston's being discussed both in relation to innovations which are based on Partch's original insights and in the context of theoretical ideas which are Johnston's individual contributions. The theoretical implications of both composers' creative practice will also be covered in cases where it suggests distinct cases which are not otherwise treated in their theorising.

3.2 Partch's Context and Legacy

Harry Partch was an early microtonal composer and theorist who exerted a strong influence on a number of later American composers both through his creative activity and his monograph *Genesis of a Music* (Partch 1949/1974), which discussed many aspects of his creative work (including extensive discussions of his own microtonal practice) alongside a narrative of historical tuning practice and scale construction. He was the most significant early American exponent of microtonal just intonation—a key strand of microtonal practice which would inform the compositional approach of a number of significant American composers and experimental music practitioners. These include Lou Harrison (1917–2003), Ben Johnston (born 1926), James Tenney (1934–2006), La Monte Young (born 1935), Terry Riley (born 1935), Tony Conrad (born 1940), John Cale (born 1942) and Glenn Branca (born 1948).[72]

3.3 Partch's Inspiration for the use of Just Intonation Intervals

In contrast to the majority of those listed above, Partch's engagement with just intonation was partly based on looking backwards to a perceived 'Golden Age', found in ancient Greek (and non-Western) practice as approached via the work of Helmholtz (Gilmore, 1998, pp.49–50), rather than a modernist's search for new musical materials (Johnston, 1984, p.228).[73] An informed and nuanced assessment of Partch's relationship with ancient Greek practice is provided by a friend, Erv Wilson, who suggested the idea that Partch 'intuitively perceived the rightness of using the unfamiliar ratios from higher in the overtone series because those relationships had existed in the music of ancient Greece and non–Western cultures' (Wilson, quoted in Gilmore, 1998, p.69). However, this analysis fails to take into account another root of Partch's investigations of Greek culture: the use of pitched materials to reinforce dramatic declamation, providing stylised versions of speech intonation. Partch himself seems to have regarded the exploration of the spoken word as the key vehicle for his artistic expression. Some initial investigations of the intonation of speech as musical raw materials can be seen in his early settings of lyrics by the Chinese poet Li Po, with the compositional results providing a continuum between transcribed speech intonation and melody (Gilmore,

---

72 It should be noted however, that not all of the composers above were *directly* influenced by Partch's theories— Johnston and Tenney are two such figures (Gilmore 1995, p.459).

73 However, it should be noted that he did share the modernist composer's ethos of 'educating' the ear to increasing degrees of dissonance (Gilmore 1998, p.62) and the result of his incorporation of subtle microtonal divisions based upon the 11–limit and a significantly increased number of intervals cannot be completely separated from musical modernism's search for novel materials.

1998, pp.76–7). By his own account, Partch (1974, p.5) notes that 'I came to the realization that the spoken word was the distinctive expression my constitutional makeup was best fitted for, and that I needed other scales and other instruments.' In this expression, it seems that the inspiration for the investigation of scales derived from an impulse similar to the ancient Greek model (music as a component part of dramatic art), with the parametric framework for this investigation provided by Helmholtz and the end result being the necessity of creating new instruments. One question which could be posed here relates to whether the accurate rendering of intonation patterns in speech requires the use of just as opposed to tempered microtonal intervals. Indeed, the aspect of a finer degree of quantisation in microtonal pitch division (as opposed to the attachment to mathematically 'correct' just intonation values) is prioritised in the notation of microtonal speech contours using tempered quartertones and sixth-tones in early drafts (circa 1930) of his Li Po settings (Gilmore, 1998, p.79).

In response to this question, it could be argued that there are two loosely—but not completely— allied impulses in Partch's microtonality: (1) a concern for the accurate rendering of speech inflection, illustrated by the fact that his Li Po settings were described as 'tone declamations' (Gilmore, 1998, p.76); and (2) a more theoretical concern for a rational system of deriving these smaller intervals, motivated somewhat by a desire for consistency in this domain. For all that his intervallic inspiration derives from just intonation intervals (and, initially, from the harmonic series), a significant (perhaps even primary) part of Partch's motivation derives from speech intonation and expressive declamation. The tracking of speech intonation and its adaptation to musical materials could not lead to a direct structural/linguistic influence upon other composers in terms of musical style unless they were using some of the same materials and methods. With this in mind, Partch's theory and practice provide a unique and historically-grounded microtonal approach which, although influential (particularly in the American context), exerts its direct influence upon subsequent work more in the the sphere of intervallic vocabulary and its theoretical development than in replications of the form and sensibility of its expression.

3.4 Partch's Corporeal Philosophy, Experimental Ethos and Resulting Creative Practice

Beyond the aforementioned extension of the intervallic vocabulary and the creation of new instruments to satisfy the demand for the accurate rendering of this vocabulary was the instruments' role as distinctive novel instruments in evoking a dramatic performance practice which is in many ways an inseparable part of Partch's aesthetic (and, indeed, inspiration). Partch termed his preferred musical philosophy *corporeal music*: 'music [which] is emotionally "tactile" [...] it does not grow from the root of "pure form"', influenced by musical traditions which unified poetry, dance and drama with music, in contrast to the predominance of abstraction in Western composition (Partch, 1974, pp.8–9). The practical rationale behind Partch's microtonality was, as noted above, that of representing expressive speech intonation; another connection with his stated philosophical aims. Indeed the corporeal utility of his microtonal intervals and new instruments sometimes went even further in referencing extra–musical materials. In performances of his mid-period piece *U.S. Highball* (Partch, 1943/1955) an onomatopoeic musical approach sees him combine ostinato rhythmic gestures and chromatics scales on his microtonal harmonium (the Chromelodeon I) with a mechanical sound effects generator[74] (constructed for the 1958 recording) to imitate 'a Southern Pacific freight train crawling through the steep pass sixty miles away, then racing down the near side' (Partch, 1974, p.251). An extremely clear example of the result can be found in the opening of *U.S. Highball* (Partch, 1943/1955, 0'22"–0'33"). Using these methods, Partch accomplishes an instrumental rendering of the soundscape of his experiences on hobo railway journeys of surprising verisimilitude, whilst still allowing him to integrate these most obviously ‘corporeal’ of gestures with his narrative and compositional logic so that he can move seamlessly between this directly representational element and music which serves more as a commentary. Thus, the use of microtonal materials in this representational context (more based on the principle of finer degrees of quantisation) is a motivating factor whose philosophical base and structural implications are similar to the representation of speech intonation discussed earlier.

Partch did not engage with a more strident modernism himself and remained grounded by his ethos in commonplace American experience of the early twentieth century. Indeed, it could be argued that he epitomised a key facet of a common conception of American identity within American experimental music—his music, after all, drew on both polyglot cultural foundations/inspirations and on a very individualistic construction of identity. This individualism, though undoubtedly a central aspect ot American culture, did not facilitate ‘direct’ success in the public reception of his own work or the development of a widely-disseminated tradition of musical construction and/or

[74] Effectively a variable-pitch acoustic siren.

performance practice.[75] However, the idea behind his individualistic, pioneering sensibility and confident and energetic engagement with the construction of a new musical language *was* influential. In this analysis, Partch is ‘the most American composer of all, the center and progenitor of our indigenous music culture’ (Gann, 1992, p.90), due to his creation of a unique musical language which is both ‘non–Eurocentric’ and ‘non–popular’ (Gilmore, 2003, p.16). This ethos of the ‘musical pioneer’ would arguably go on to influence a range of composers not simply limited to the microtonal sphere, but also including the ‘perceptual–conceptual’ work of Alvin Lucier and James Tenney, whose rigorous extensions of musical materials and language were both singular in approach yet grounded in perceptual phenomena (a parallel with Partch's investigation of tuning through the lens of speech intonation and non-Western musics).[76]

---

[75] In part, this was undoubtedly due to the logistical difficulties inherent in the development of new instruments with unfamiliar intervallic vocabulary, in part, perhaps, due to the culture clash between Partch's autodidactic and pioneering ethos and conservative institutional culture in the shape of funding bodies and universities which still emphasised models derived from Europe (Gilmore 1998, Chapters 4, 6, 7); see also (Gilmore, 2003, p.16). Gilmore (1998, p.157) has further noted that the work in preparing *Genesis of a Music* for publication could be seen as a bid for academic legitimacy––a bid which was only partially successful in terms of his difficult relationship with the host institution, the University of Wisconsin at Madison, and other academic institutions.

[76] John Cale has observed a common denominator for a broad cross-section of twentieth century American music based on a sort of negative capability of the emptier parts of the continent and both the 'perceptual-conceptual' approach and the less novel 'representational'/programmatic approach:

‘Copland was to me a quintessential figure in American music, whose style encompassed the haunting majesty of the open Midwestern plains. The connection between that style and the abbreviated concept in La Monte's '5th—Hold for a very long time' [*Composition 1960 #7*] was very clear to me if not to him. It was a summation of a purely American sensibility' (Cale and Bockris, 1999, p. 43).

In this construction, the emptiness of the landscape could be seen as encouraging a search for movement and/or form within more static or slowly evolving materials for the 'perceptual-conceptualists'.

3.5 Partch's Microtonal Theorising: Interval Subdivision, Scale Construction and Spatial Maps

Partch's theories are set out in *Genesis of a Music* (Partch, 1974), the initial draft of which was begun in 1928 as *Exposition on Monophony* and subsequently underwent a number of significant revisions and expansions—as many as five by 1933—before being revised for publication at the University of Wisconsin at Madison from 1944–1947 ; see the accounts of Wiecki (1991, pp.43-66) and Gilmore (1998, pp.61, 157–179). At the root of Partch's account of just intonation is his Pythagorean conviction that consonance is based on small number integer ratios, an intuition which is nonetheless shorn of its mysticism and grounded in a proto–psychophysical rationale.

> [T]he ear consciously or unconsciously classifies intervals according to their comparative consonance or comparative dissonance; this faculty in turn stems directly from the comparative smallness or comparative largeness of the numbers of the vibrational ratios; and the faculty of the ear to bring definitive judgements to comparative consonance decreases as the numbers of the vibrational ratio increase. (Parch, 1974, p.87)

This model of the relative consonance/dissonance of pitches is known as the *periodicity model* (see introductory discussion in section 1.3.3). As Roederer (2008, p.171) notes, it is a particularly attractive model due to its mathematical simplicity, based on the assumption that 'for some unspecified reason our auditory system "does not like beats"'. This association of relative consonance/dissonance with periodicity is the obvious basis for preferring the accuracy of tuning engendered by just intonation to the approximations provided by equal temperament.[77] For the microtonal composer, it has the twin benefits of facilitating the specification of a wide variety of new interval sizes (i.e. it has utility in procedural scale definition) whilst also providing an elegant means of comparing their properties with respect to consonance/dissonance judgements (a key musical property of scalar materials which can be used to compare intervals, at a higher level of organisation, the relative degree of consonance/dissonance which is permissible within particular scale structures).

Partch's musical thinking on the topic of scale structure underwent a number of stages of development from 1928 to 1935, whilst remaining fundamentally based on the just intonation principles noted above; Gilmore (1998, pp.63–5) provides a summary of these developments. Partch initially defines a twenty–nine division just intonation system (within the 11–limit[78]) in 1928, though containing large gaps, leading to subdivision based on the tuning of simple intervals (termed 'secondary ratios') above various degrees of the scale. Scale divisions varied from as low as twenty–nine and as high as fifty–five, before Partch finally settled on a forty–three–tone scale in *Genesis of a Music* (Partch 1974, pp.133–5, 154–7), see figure 17, next page.

---

[77] However, the principle whereby the intervallic approximations provided by temperaments are frequently taken as recognisable renderings of just intonation 'prototypes' with the original consonance/dissonance properties of the 'prototype interval' relatively intact implies that consonance/dissonance judgements may not be so simply defined. The significance of this aspect of approximation for microtonal scale construction and usage is discussed further with respect to Johnston and Tenney and is treated in the context of current psychological research in chapter five.

[78] Just intonation system including ratios comprising (prime) factors of eleven or less, see introduction to the concept of prime limits in tuning systems in section 1.4 (introduction).

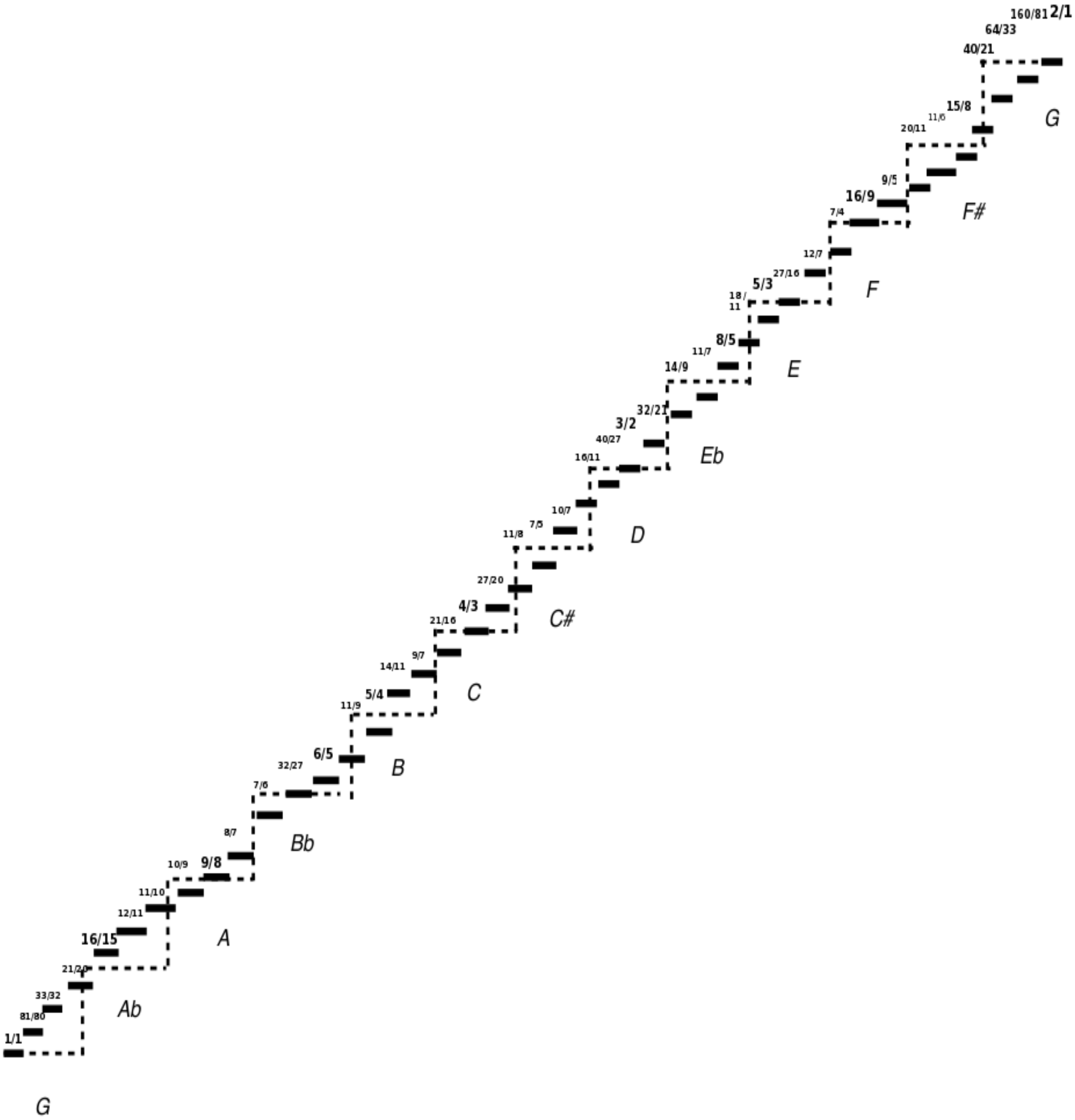


Figure 17: Partch's 43–tone scale, illustrated in comparison with standard 12TET intervals

Adapted from Partch (1974, p.134). with the addition of full ratios for the highest four intervals (which are omitted in the printing of the original version.

It should be noted that Partch appears to imply a somewhat hierarchical approach in his diagram. More familiar intervals (9/8, 5/3, 5/4, 6/5, etc.) are denoted in larger typeface than some of the more novel divisions (8/7, 7/6, 32/27). However, when compared to Partch's more empirical subsequent assessment of relative consonance/dissonance (Partch 1974, pp.154–7), this initial hierarchical presentation appears to be based more upon familiarity of interval in terms of established/historical practice in Western music and simple subdivision of established category than on any completely rigorous hierarchical basis of attributes such as consonance/dissonance. That said, there certainly appears to have been some hierarchy of categorical recognition of intervals for Partch, for his microtonal scale does appear to incorporate another level of organisation in the larger divisions, which, as Gilmore (1998, p.65) notes, incorporate versions of all of the standard Western twelve–division intervals.[79]

A further aspect of this multiplicity of intervals surrounding familiar scale divisions is to be found in an earlier account of Partch's on microtonal subdivisions which are discussed as varieties of *established* categories, with microtonal practitioners and musicians assumed to hear them as different 'shades' of a given interval, i.e. a variety of types of major third is heard, just as a visual artist can perceive a wide variety of red hues from carmine through to ochre (Partch, 1940, p.159). In this way, he descriptively asserts the categorical validity of microtonal intervals as subsidiary categories of more established intervals. In addition, apart from the pioneering act of dividing the octave into microtonal just–intonation–based intervals for the purposes of composition, Partch's method of scale construction engages with the issue of formal relationships

[79] This hierarchy on the basis of familiarity may also serve didactic purposes.

between the ratios which describe scale degrees. As Gilmore (1995, p.463) notes, ‘it was Partch's understanding of ratios and their relationships that gave him the principles that generate his microtonal scale’. This tracing of the formal (imathematically–based) relations between interval ratios led him to provide a graphic aid to his analysis of this pitch–space, his *tonality diamond* (Partch, 1974, p.110), see figure 18(a), below.

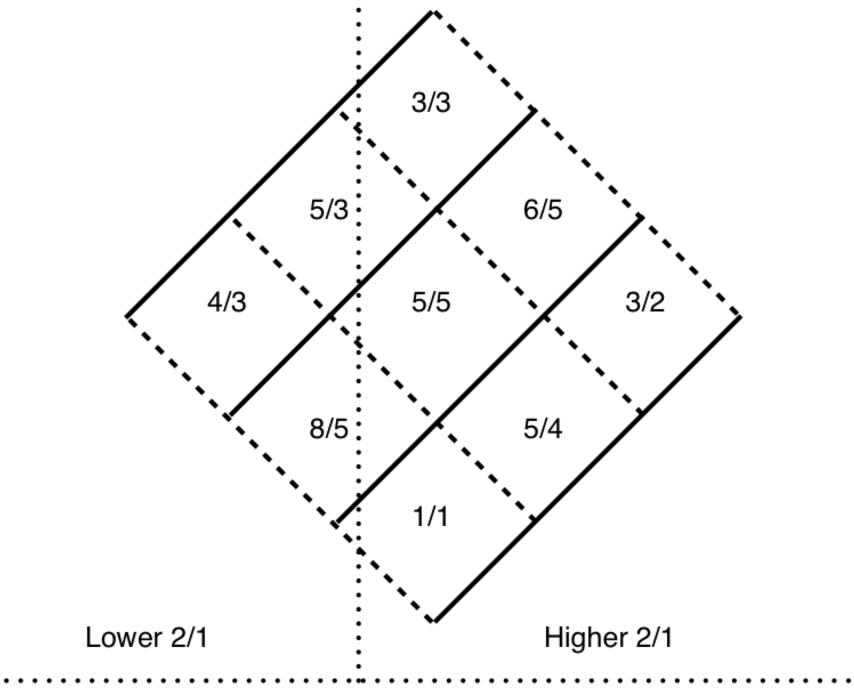


Figure 18(a): 5–limit diatonic tonality diamond (termed Incipient Tonality Diamond in Partch) after Partch (1974, p.110)

This figure is used by Partch to geometrically represent triadic relationships within the 5–limit just diatonic scale. The central vertical column comprises different means of stating a scale root of 1/1. Diagonal connections trace triadic relationships, with valid relationships separated and denoted by broken and unbroken boundary lines respectively. Thus, a triad may be obtained from 1/1, 5/4, 3/2 (via broken lines) or 4/3, 8/5 and 1/1 (via unbroken lines). The lower section relationships with familiar 5–limit interval ratios ('lower 2/1'—lower octave) are made clearer by the restatement of interval ratios within one octave between 1/1 and 2/1. A 'correctly spelled' version of this tonality diamond is provided in figure 18(b).

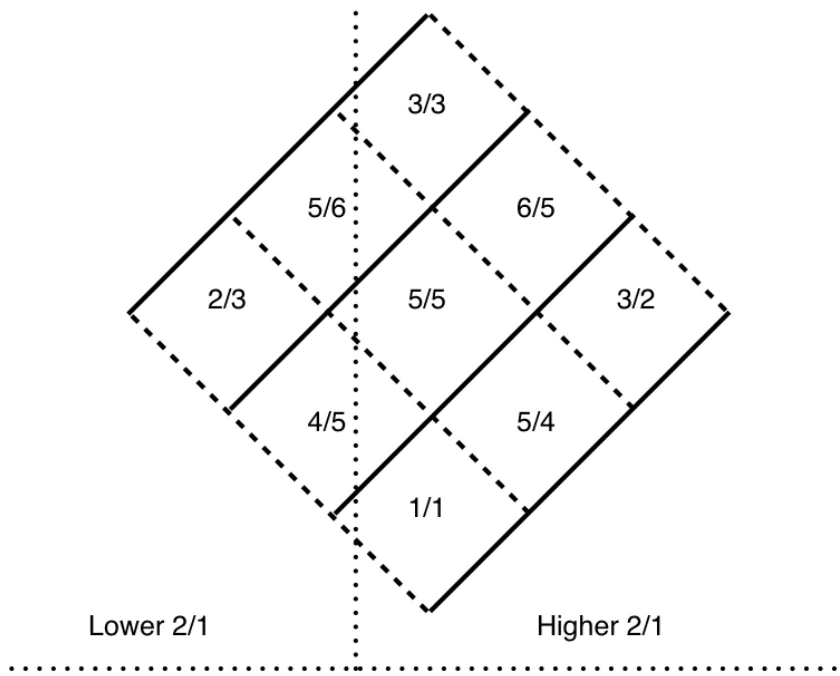


Figure 18(b): 5–limit diatonic tonality diamond: formal connections clarified through correct (untransposed) statement of lower intervals; adapted from Partch (1974, p.110)

This type of representation owes a debt to the spatial representations of Euler (from 1739), reprised and developed by Oettingen (from 1866) and Riemann (from 1880), the initial motivation being the description of connections between different just intonation materials; a history of development of this approach is provided by Cohn (1997, pp.170–3; 1998, pp7-10). In this regard, Partch's tonality diamond is influenced directly by Riemann and Oettingen; cf. Partch (1974, p.390). The general two-dimensional lattice-based layout of Euler (and by extension, his successors) can be seen below (figures 19 and 20), termed the *Tonnetz* in Euler and successive works—cf. Euler (1739) and Cohn (1997, pp.170–3).[80]

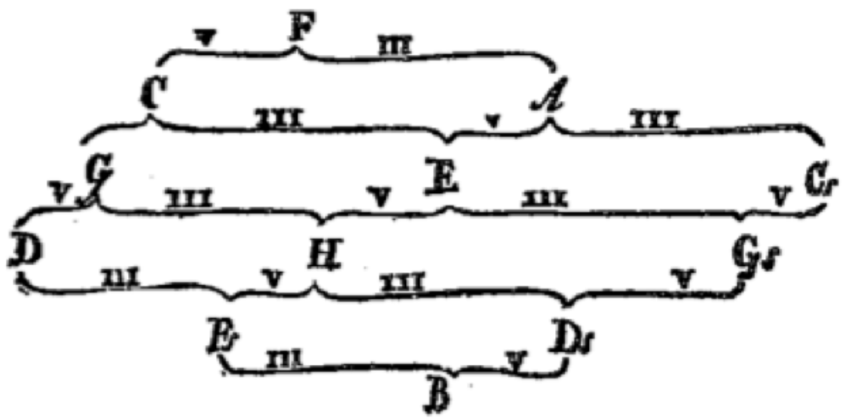


Figure 19: Euler's Tonnetz *diagram from Euler (1739, p.147)*

This indicates intervallic relationships of major thirds (indicated by III) and perfect fifths upwards (indicated by V). Note that the diagram is inverted in comparison with more modern representations, proceeding downwards to go upwards in pitch/interval.

[80] Such representations are also sometimes termed *Euler-Fokker genera* in microtonal music circles, cf. discussion of Fokker (1955) in chapter two.

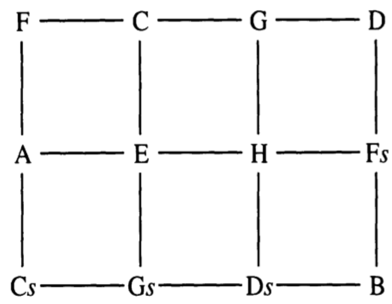


Figure 20: Euler's Tonnetz *as depicted in Cohn (1998, p. 7)*

The fifth relationship is now on the horizontal axis (left to right), with the third relationship indicated on the vertical axis (downward direction).

It should be noted that the intervallic representation within Euler's original *Tonnetz* (and Oetingen's reprise), like Partch's tonality diamond, is designed to signify the just intonation intervals, rather than general classes of intervals/pitches (Cohn, 1997, p.7).

3.6 Defining and Developing Relationships: Major (Otonality) and Minor (Utonality) Paths and Extended Just Intonation

Expressed without the aforementioned modification, the interval relationships between higher and lower octaves are much clearer: the ratios are inverted for the lower intervals. Thus, moving downwards from 1/1, the middle note of the triad has a 4/5 relationship with the original frequency, with the final note being 2/3 of the frequency. Partch terms the relationships moving upward in frequency (diagonally to the right) *Otonality* and the relationships moving downward in frequency (diagonally to the left) *Utonality*. In their transposed/octave folded form, the Utonality relationships describe the minor sixth (8/5), minor third (5/3) and the subdominant (4/3). Minor triads may be completed by following the Utonality relationships diagonally downwards. This representation illustrates the formal relationship between two parallel systems which have developed in Western music since the Renaissance—major and minor tonalities. The major intervals from the diatonic scale (along with the perfect fifth) can be viewed as being derived directly from intervals found within the harmonic series, i.e. the relationship between these harmonics expressed as frequency ratios and the fundamental, folded back within one octave.[81] See figure 21, below, next page, for an illustration of 5–limit diatonic intervals derived directly from harmonic series relationships with fundamental.

---

[81] Jean–Philipped Rameau, the pre–eminent French composer-theorist of the eighteenth century, regarded the early ratios of the harmonic series as the root of harmony, though this elegant principle did not fully explain why integer ratios which are not obtained directly from the harmonic series (such as minor thirds and sixths) can still create consonant configurations (Rameau, 1722, cited in Benson, 2006, p.141). See section 1.3.3 (in the introduction) for further detail regarding Rameau's theories and his legacy.

Harmonic series and 5–limit diatonic intervals generated from relationships with fundamental or octave of same

1/1	**2/1**	**3/2**	**5/4**	**9/8**	**15/8**
root	**octave**	**perfect 5th**	**maj. 3rd**	**maj. 2nd**	**maj. 7th**

5–limit diatonic intervals generated through relationships between harmonics other than fundamental (or octave of same)

4/3	**5/3**	**9/5**
perfect 4th	**min. 6th**	**min. 7th (5-limit version)**

Figure 21: Harmonic series intervals and the derivation of 5–limit just diatonic intervals

As can be seen from the above, the minor intervals do not correspond *directly* to those harmonic series interval relationships which are expressed in relation to the fundamental, but some can be derived from relationships *between* harmonics (such as the 6/5 minor sixth between the fifth and sixth harmonics and 5/3 minor third between the third and fifth harmonics; the perfect fourth 4/3 can also be derived in this way). Such relationships could also be conceptualised as deriving from an inverted harmonic series, working downwards from a given initial pitch reference. However, Partch does not draw any particular distinction between these two types of interval relationship—the formal proportional relationship is considered to be the arbiter of pitch-based structure.

This is congruent with his more general position, which disregards any direct structural correspondences with harmonic series structures:

> Long experience in tuning reeds on the Chromelodeon convinces me that it is preferable to ignore partials as a source of musical materials. The ear is not impressed by partials as such. The faculty—the prime faculty—of the ear is the perception of small-number intervals, 2/1, 3/2, 4/3, etc., etc., and the ear cares not a whit whether these intervals are in or out of the overtone series. (Partch 1974, p.87)

From Partch's perspective, the significance of this approach was that it led him to consider a wider range of interval relationships which do not necessarily occur directly within the harmonic series, although some such interval relationships may be conceptualised as approximations of harmonic series intervals which feature higher prime numbers than three or five as factors. This extension of the just intonation principle contributes to the formation of scales which are grouped under the rubric *extended just intonation.*[82] Following the principle by which 3–limit Pythagorean tuning was extended to 5–limit Ptolemaic tuning (in cases of intervals which can be expressed using simpler integer ratios using higher primes as factors), Partch notes that intervals based on the 7–limit—the next prime[83]—may be implied in certain intervals used in Western music (most particularly, sevenths), but not specified with exactness; he elaborates that inertia engendered by fixed–tuning solutions is the cause of this situation (Partch, 1974, p.120,125–6). Thus, the 7/4 minor seventh is taken as a generalised interval type to be rendered via substitution with 5–limit (or lower limit) counterparts

---

[82] A general category of scales which are constructed based on whole-number ratios which exceed the 5-limit found in earlier instances of just intonation. See further discussion in the next section (in relation to dimesnionality and functional identity) with particular reference to the work of Johnston.

[83] Indeed, as Gilmore (1995, p.467) notes, it is Partch's explicit assumption that a clear historical progression can be traced in Western music's incorporation of higher prime-based intervals.

such as 16/9 (3–limit) or 9/5 (5–limit). However, these intervals are not microtonal in themselves, though the different versions of the generalised interval type may form microtonal relationships with each other.

With this in mind, Partch justifies what he terms a further 'break' to 11–limit[84] divisions on the basis of an assertion that human abilities regarding pitch discrimination are significantly greater than is generally assumed in the construction of scales with larger (i.e. non–microtonal) intervals, justifying this on the basis of some early (1920s and 1930s) psychological research and theorising regarding pitch discrimination abilities in the context of sequential presentation (Partch, 1974, p.121–2). A commentary on more recent findings regarding pitch discrimination abilities will be provided in chapters five and six. For the present purposes, Partch's theories will be further discussed on the basis of his working assumption that such microtonal discrimination abilities are possible, in addition to reflecting a structural rationale whereby harmonies implied by seven, nine and eleven as factors in their ratios are approximated in an unsatisfactory manner (through 12TET chromatic intervals) within a 5–limit–based conceptual framework (*ibid.,* p.125). Partch does not rule out the use of 13–limit scales, but regards the number of scale divisions available in 11–limit to be sufficient as a preliminary extension of the intervallic vocabulary (*ibid.,* p.123).

---

[84] Some aspects of Partch's discussions raise the issue of distinctions between factors based on prime-limits or *odd-limits* (which would, for examle, encompass 3-prime-limit compounds such as 9-based ratios)—cf. Erlich (1997), who terms the odd-limit a *Partch limit*. Anders and Miranda (2011) seem to follow this interpretation. This is presumably referring to the discussion in Parch (1974, pp.93,126), where 9 is discussed as an interval identity, though not a prime. In essence, odd-limit as a concept elaborated from the Erlich interpretation of Parch provides a useful scale for numerical complexity of an individual interval; prime-limit is of utility in terms of scale structure (i.e. dimensionality)—c.f . Anders and Miranda (2011). My own assessment is that Partch's account is (also) informed by prime-limit thinking (e.g. pp.120–127) in its structure, further corroborated by the dimensionality (based on prime-limits) implied in his progression of tonality diamonds which, according to Gilmore (1995, p.467) includes a 17-limit instance in addition those outlined in Partch (1974).

3.7 Extended Spatial Maps: Theoretical Model to Interface to Formal Structures

Partch's exploration of ratio–based pitch relationships leads him to expand his tonality diamond to encompass 11–limit intervals; see figure 10, below (Partch 1974, pp.158–9). This is expanded from Partch's 5–limit arrangement to include all primary Otonality and Utonality ratios of eleven, expressed with ratios as if within a single octave. As before, Otonality relationships are traced via diagonal lines to the right in rows bounded by solid lines, with Utonality relationships traced via diagonal lines to the left in rows bounded by dotted lines. The frequency ratios are arranged in size such that horizontal deviations from the centre line (denoting unison) to the right and left denote increased interval sizes.

The resultant *Expanded Tonality Diamond* (figure 22, page after next)—based on his 5–limit 'Incipient Tonality Diamond')—continues to represent pitch relations on a two–dimensional plane, with consonance and dissonance not being treated directly but with formal mathematical relationships between intervals clearly visualised. Indeed, based on the ratio–simplicity assumption inherent in a periodicity–based theory of consonance, such a construction may provide a pathway *towards* a more comprehensive representation of consonance and dissonance through the illustration of these ratio relationships. As Gilmore notes, this representation found usage in the interface of Partch's instruments (Gilmore, 1995, p.465); the Diamond Marimba instrument is explictly highlighted by Partch as the 'theoretical Tonality Diamond brought to practical life' (Partch, 1974, p.261). Potential chords are represented through these diagonal rows of diamond–shaped cells, with an expansion to include sevenths, ninths and elevenths, ‘folded’ within an octave. Thus, a chord (or scale) featuring harmonic series intervals can be created by following a diagonal track from 1/1 through 9/8, 5/4, 11/8, 3/2 to 7/4 (arranged in order of size when reproduced within one octave), or, following more standard/‘orthodox’ theories of harmony, a chord/scale constructed in major thirds, with 1/1, 5/4, 3/2, 7/4, 9/8 (in compound form 9/4), 11/8 (in compound form 11/4)—thus 1–3–5–7–9–11 (*ibid.,* p.160).

In addition, small size variations on given intervals can be found on the vertical axes (with the exception of the central column), such as the 9/8 major second extending through 10/9 (the 5–limit minor whole-tone) through an eleven–based version of the same to the 7–limit minor third 7/6 (also termed a *septimal* minor third due to its 7–limit nature). It should be noted, however, that this column does not denote an increase in interval size on the vertical axis, and 10/9, 11/10 and 12/11 are smaller than 9/8 (though the last interval is significantly larger). The twenty–nine distinct interval ratios here (when simplification has rationalised, for example, the 12/9 and 4/3 and 9/6 and 3/2 ratios) are part of Partch's scale construction process, with some subdivision of larger gaps through the addition of extra intermediate intervals created through movement by small-number integer ratios (*ibid.,* p.156). The total number of interval relationships implied by the resultant scale structure is, however, much higher, as 340 distinct interval relationships are created through relationships between each of the different 43 scale divisions: 43*43=1,806, which results in 340 distinct interval ratios when each ratio is expressed in its simplest form (*ibid.,* pp.156, 461–3). The implications of this number of intervals for the representation of pitch-space will be discussed below.

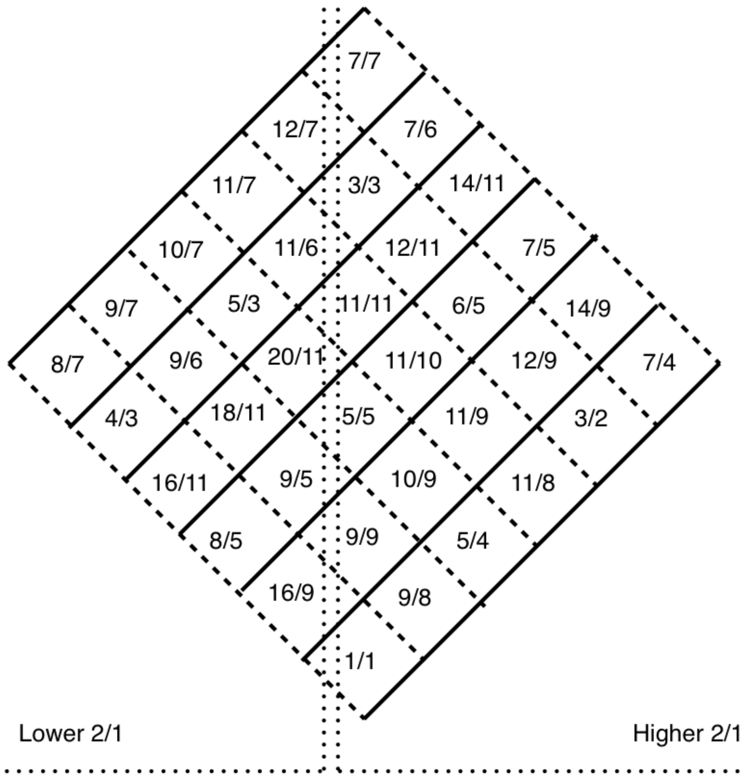


Figure 22: Partch's 11-limit Expanded Tonality Diamond—after Partch (1974, p.159)

Gilmore (1995, p.467) discerns an implied dimensionality in Partch's treatment of interval relationships which was absent from much earlier (nineteenth and early twentieth–century) treatments of pitch as a parameter, focussed as they were on a one-dimensional representation:

> It is perhaps not too fanciful to see in the Diamond image and in Partch's other early models of pitch space a latent *dimensionality*,which seems all the more iconoclastic given the prevailing tendency of the models in the standard literature: Helmholtz (1863), Mach (1906), and Koffka (1935)] of the time. (Gilmore 1995, p.467) [italics in original]

In contrast, Gilmore regards Partch's engagement with graphic representation of formal relationships as a positive contribution to the sophistication of the treatment of pitch, though it is important to note that it does not *directly* address issues of consonance judgements or perceived relationships between pitches based on experimentation rather than theorising (*ibid.,* p.467–8) . Nonetheless, as Gilmore goes on to note, it does conform to the theory of a two-dimensional pitch percept based on a division into *pitch-height,* i.e 'absolute' pitch difference, encompassing entire frequency range of pitch sensitivity, and *pitch-chroma,* based on discernible scale divisions/identities within the space of a single octave, repeated at different pitch–height octave offsets (*ibid.,* p.467).[85] The idea of 'folding' a range of pitches—obtained through repeated processes of transposition by a given interval—into a single octave is undoubtedly compatible with a grid–based representation such as Partch's tonality diamonds. These formal representations of pitch-space undoubtedly provide insight into possible formal relationships between interval ratios. Indeed, a further extension of Partch's 11–limit diagram, restructured as a set of overlapping pentagons in a multi-dimensional space provides an elegant means of representing a complex and overlapping set of Otonality and Utonality relationships (Wilson, cited in *ibid.*, p.468). Chordal relationships derived from the tonality diamond are frequently found as forms in Partch's music (Gilmore 1995, p.469) and undoubtedly provide him with a conceptual (and, therefore, compositional) framework for pitch structures. However, as noted earlier in this section, consonance and dissonance are not treated directly using this method of representation and do not form a significant part of its organisational structure (though it is possible to examine these graphic structures for the relative simplicity of the ratios on the basis of the periodicity model of consonance/dissonance). From this point of view and with

---

[85] A similar division in music theory relating to interval and register obviously predates and anticipates this theory.

reference to the focus on perceptual issues in this present project, Partch's other method of representing his pitch-space is of more immediate interest and significance here. This second method of visualising pitch–space has the benefit of prioritising consonance/dissonance judgements as a central part of its representational structure, in addition to a derivation which is empirically grounded in a process of interval listening and comparison.

3.8 Partch's Model of Consonance/Dissonance Relationships

A more empirically–based model of pitch relationships is to be found in Partch's 'One-Footed Bride' (see figure 23, next page), as he terms his diagram based on a relative assessment of consonance/dissonance of certain intervals on the basis of Partch's own judgement[86] (Partch 1974, pp.155–6). Partch appears to be aware here of the difficulties associated with relying solely on formal representations and logical deductions without recourse to empirical findings, noting that a diversity of consonance and dissonance judgements can be present within the 340 interval relationships which result from his 11–limit scale (*ibid.,* pp.154–156). He also notes that the illustration of consonance ratings for his scale's 340 distinct intervals would be unwieldy but that an illustration of his forty–three interval division of the octave establishes distinct regions of difference in consonance/dissonance. Thus, the forty–three tone scale is reinforced as the perceptually–important structural level within Partch's system.

86 At least, if any other individuals were involved in this assessment, Partch does not acknowledge or name them.

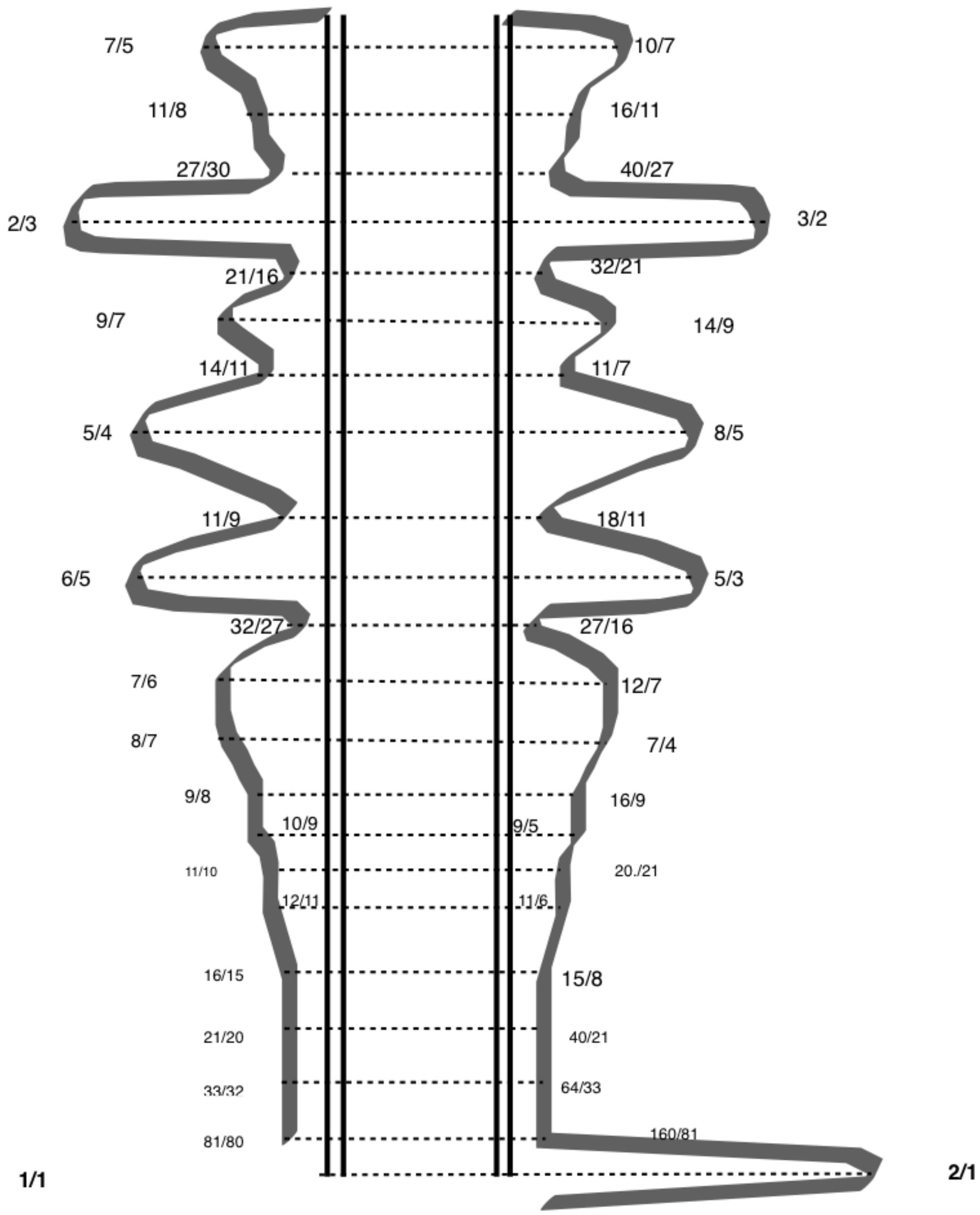


Figure 23: The One-Footed Bride: graph of 'comparative consonance', after Partch (1974, p.155)

Partch also admits a further hierarchical refinement with some adjacent intervals possessing similar degrees of consonance grouped under headings such as ‘power’ (fifth/fourth), ‘suspense’ (variants on the tritone), ‘emotion’ (variants on thirds and sixths) and ‘approach’ (variants on whole-tones, semitones and sevenths). Thus, whilst the distinctiveness of novel microtonal intervals is highlighted in this representation, a certain degree of hierarchical rationalisation is present at another level of organisation. Regarding the lack of specificity in his graph regarding conditions such as spectral content and register—influencing factors which he had discussed previously (*ibid.,* p.153)—Partch nonetheless anticipates methodological criticisms, noting that:

> it is fairly foolish to undertake to pin consonance to a graph less general than this unless it is predicated on specific range, specific quality of tone, specific relevance of combinatorial tones, and specific assurance that these qualitative and quantitative factors are invariable. Short of a lifetime of laboratory work which the composer cannot undertake, the general is the only practicable approach. (*ibid.*, pp.156–7).

The resulting graph of consonance/dissonance judgements, if it were to be verified, would offer a degree of endorsement of the basic salience of microtonal intervals and their perceptual distinctiveness. Even if every single interval were not to be distinct, the difference traced in perceived consonance appears to imply significant degrees of difference in consonance for over twenty intervals within the octave (when adjacent intervals graphed as possessing similar degrees of consonance are eliminated).

In fact, Partch appears to have been a particularly careful listener—as Sethares (2004, p.89) notes—and his graph bears striking resemblance to the later findings of Plomp and Levelt[87] (1965, pp.553–6) relating to assessments of consonance and their mechanism, investigating the theories of Helmholtz surrounding the association of

[87] See section 1.3.3 in the introduction.

consonance/dissonance with the presence or absence of audible beat frequencies between partials and refining it in relation to the critical band response of the basilar membrane. Plomp and Levelt's study (*ibid.*) carried out subject-testing of dyads created by two sinusoidal oscillators, confirming an association between what are termed *tonal consonance* judgements and the critical band response in the inner ear. In such cases, pairs of sinusoidal components are registered as possessing the attribute of dissonance if their frequency difference is less than a given frequency bandwidth (the critical band), with maximum consonance (or minimum dissonance) judgements relating to exceeding 100% of this bandwidth (*ibid.*).

An earlier study (Kaestner, 1909, cited in Plomp and Levelt, 1965, pp.551) had produced findings for the the *degree* of consonance (strictly speaking, 'pleasantness') found at various intervallic positions when studying complex periodic tones.These findings do not correspond exactly to Partch's assessment of consonance but nonetheless produce correspondences for the positions of consonant peaks, which are found at important nodes of 16/15, 9/8, 6/5, 5/4, 4/3, 7/5, 3/2, 8/5, 5/3, 9/5, 15/8 and 2/1 (matching similar nodes in Patch's representation). In addition, the *degrees of consonance* match Partch's judgements in relative terms (*ibid.*). Whilst a much smaller range of intervals than Partch's 11–limit intervals are highlighted here, thirty intervals within the octave were tested (hence, a presentation of microtonal materials) and clear consonance/dissonance distinctions at intermediate points between certain adjacent intervals were discernible, endorsing a view pertaining to the perceptual distinctiveness of microtonally–based dyads. This may imply one possible mechanism behind the recognition of microtonal intervals. In addition, some degree of corroboration is provided for the connection between small integer ratios and harmony which theorists had previously assumed.

Complex periodic tones were next considered computationally by Plomp and Levelt (*ibid.*), extrapolating from their pure–tone model, producing results which corresponded with the experimental findings of Kaestner (see above) and, as noted by Sethares, the informal experimentation carried out by Partch. When the findings in relation to critical bandwidth were applied computationally to cases where tones with six harmonic partials were combined as dyads, consonance judgements whose position *and* degree corresponded closely to Partch's findings were predicted (see figure 24, below, next page). The assumptions in this case were that total dissonance for the complex dyad was related computationally to the sum of critical band dissonance rating for individual pairs of partials. Furthermore, extra peaks and troughs were predicted for ratios comprising higher harmonics (e.g. seventh, eighth) where these were present in component tones.

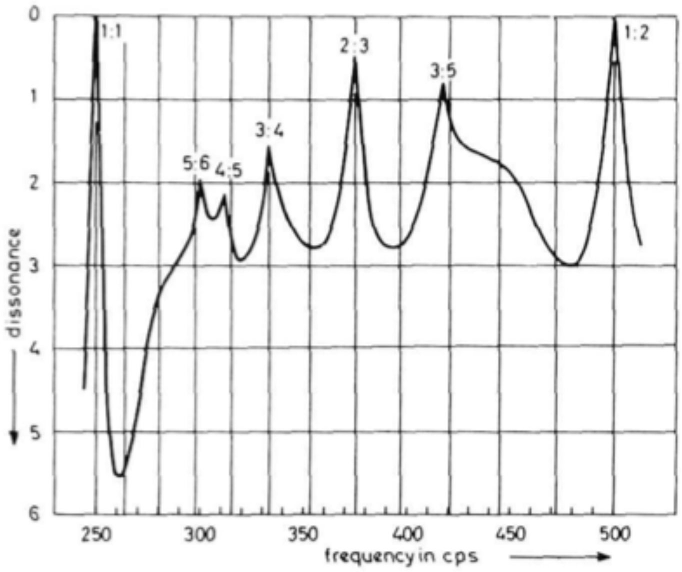


Figure 24: Plot of dissonance judgements for dyads based upon complex tones with six partials, from Plomp and Levelt (1965, p.556)

Sethares (2004, p.86) terms such graphs 'harmonic dissonance curves'.

Peak consonance is to be found at positions described by whole number ratios rather than occurring at points which are strictly aligned with the tempered 12TET scale (Sethares, 2004, p.93) thus providing support for the deployment of just intonation in the context of seeking out consonant configurations *for harmonic timbres in simultaneous* combinations, at least in this sensory–based view of consonance. Microtonal steps are not indicated explicitly in this representation (and note the absence of peaks/troughs related to partials higher than the sixth), but the general shape again closely resembles Partch's figure, corroborating his ideas based on this theory of sensory consonance/dissonance responses. In addition, some of these relatively defined intermediate peaks and troughs appear to suggest intervals of intermediate consonance/dissonance other than the larger intervals shown here. The broad findings of the Plomp and Levelt model were later verified experimentally by Kameoka and Kuriyagawa (1969, pp.1464–9), thus indirectly corroborating the similar findings of Partch.

Thus, significantly, Partch is shown to be an early practitioner–theorist who developed a model based on the Pythagorean assumption that simple integer ratios are somehow perceptually significant but refined by means of careful testing of intervallic materials, producing an extensive perceptually–informed catalogue of consonance judgements and, by implication, perceptually–based microtonal distinctions. However, although Partch's graph provides a useful perceptually–grounded refinement on the simple Pythagorean view of consonance/dissonance, he does not fully engage with one of its implications: that some very small just–intonation microtonal intervals or minor variations on larger microtonal intervals may produce consonance judgements which do not differ to a significant degree. Thus, although he produces a rationalised scale of forty–three divisions from the proliferation of possible just intonation intervals contained on a graph which indicates similar or identical consonance/dissonance judgements for many adjacent intervals (and groups of intervals), he does not explicitly revisit his initial point of departure regarding the use of simple integer ratios to define intervals.

Although Partch’s graph does not indicate intermediary steps between the forty–three intervals and so cannot be expected to account for cases of mis–tuning, it could be argued that if 21/20 and 33/32 produce perceptually similar results, there may be a degree of perceptual or cognitive 'data reduction' at play which would allow for a degree of tolerance in interval specification. If Partch's work had directly addressed this implication, it would have been of even greater lasting value. Nonetheless, through his grounding of his theorising with his composer's experience and a personal process of listening and interval categorisation, Partch made one of the most significant contributions to a perceptually–grounded theory and practice of just intonation microtonality.

3.9 Partch's Compositional Practice in Relation to his Theories

The connection between Partch's theoretical work and his compositional practice is somewhat problematic, an issue noted by both Rasch (2000, p.26) and Gilmore (2003, p.20), the latter quoting Rasch to exemplify a musicological position which is sceptical of Partch's lack of consistency in this regard. One aspect of this criticism—that focussed upon by Rasch—highlights an inconsistency in relation to the interaction between Partch's theories of tuning practice and the instruments which he chose to implement this these tunings on. With a few exceptions (such as the Chromelodeon), Partch tended to favour:

(1) percussion instruments (possessing inharmonic spectra in which intervals with simple integer ratios would not necessarily produce consonant combinations where partials deviated significantly from the harmonic series)

(2) plucked or struck string articulations (which would not sustain sounds for significant periods of primarily harmonic equilibrium after the attack transient, producing less than ideal conditions for the perception and recognition of variations in consonance for subtle changes in intonation).

Neither case was particularly helpful with regard to the clearest possible practical implementation of Partch's theories: Rasch (2000, p.26) opines that the result reduces the impact of the presentation to a vague awareness of 'intonational color' in a context where it is difficult or impossible to judge the details of the intonation. Similarly, Carlos (1987, p.37) considers this to be 'Partch's folly': that he primarily favoured inharmonic instruments with rapid decays and relatively rapid runs of notes such that he 'hid' the effect of his tuning. Gilmore, perhaps a little more sympathetic (and possibly trying to dismiss this difficulty, notes a 'creative anarchy' in Partch's approach which prioritised the striking novelty of his new instruments (Gilmore, 2003, p.20). In doing so, he further notes the approval of Partch's just intonation colleague Lou Harrison of a moment in Partch's *Windsong* (1955) where irrational pitch relationships are obtained by playing behind the bridge, highlighting a case of a clear attachment to a more *ad–hoc* use of irrational pitch materials. A further explanation is that a presentational style which highlights less commonplace instrumental timbres could be directly aligned with Partch's philosophy of corporeality. Indeed, as noted above, Partch's concern for theoretical consistency may not have been completely allied with some of the practical requirements of his music, beyond the demand for finer degrees of pitch quantisation.

Beyond the issue of instrument articulation and timbre, Partch was often more concerned with deploying these intervals in a sequential/melodic fashion—initially for the rendering of vocal lines. However, in later, in pieces such as the dance piece *Daphne of the Dunes* (Partch, 1967, 2'22"), just intonation instrumental melodic lines on the kitharas arpeggiate harmonic figures over a drone, thus providing a reference point for consonance/dissonance assessment.[88] In addition, whilst the use of microtonal materials in predominantly monophonic/monodic contexts (or with mostly brief plucked articulations) does not derive direct support from the experiments with dyads noted above, the intervals so obtained could nonetheless be viewed as prototypes for melodic intervals. Partch's concern for theoretical consistency could thus have balanced concern for numerically-based rationality of the Pythagorean-style order (in sequential contexts) with the observable physical reflection of that order in simultaneous contexts. Therefore, even if the choice of melodic/sequential intervals is derived from experiments in simultaneous sonorities, this does not necessarily indicate a complete theoretical inconsistency.

Indeed, Partch highlights the issue of theoretical consistency in the following discussion:

> I do not always achieve the just intonation which I hold as desirable—the clear choice of consonance or dissonance. Someone has said that ideals are like stars.We can't touch them but we look to them for guidance. I believe in a rational—that is, acoustical—approach to the problems of musical materials, as the only one leading to genuine insight.
>
> (Partch, quoted in Gilmore 1995, p.460).

The accuracy of pitch perception in melodic/sequential contexts nonetheless represents a significantly different case in auditory perception; even if the interval sizes are derived from tunings in simultaneous tunings, the discrimination of microtonal intervals may be

---

[88] Partch's instruments based on the kithara model provide a more helpful degree of sustain than some of his other plucked string instruments.

expected to be somewhat different from simultaneous cases, given the lack of beating harmonics in such presentations. In sequential contexts, the principle of accurate adherence to integer ratios implied by the minimising of acoustic beating effects is modified somewhat and such intervals may deviate from these ideals, as admitted in the above quote from Partch. In sequential cases, the limiting factor in discrimination is different and although the effect of mis-tunings in sustained integer–based intervals is immediately obvious (due to beating effects), discrimination might be expected to be less accurate without such an aid. Even in the melodic context, microtonal discrimination abilities are significant, with a series of experiments investigating sequential presentations for frequency discrimination yielding results which yielded frequency difference sensitivities of approximately 1/12 of a semitone (Zwicker et al., 1957, pp.556–7; Roederer, 2008, p.33). Although McAdams (1989, p.184) notes that Partch's system may approach the limits of discriminability, most of his interval sizes exceed this size by a reasonable margin (Partch, 1974, p.133).[89]

Thus, the perception and accuracy of reproduction of such intervals is but one factor in their viable compositional deployment. The performance practice of singers in Partch's pieces suggests that some degree of sequential microtonal intervallic recall is possible; even if the composer himself admits that such cases may not always fully align with ideal just intonation tunings, such tunings could be considered to function in the manner of creating intervallic prototypes which are approximated melodically. Aspects relating to limits of discriminability and cognitive organisation of scales will be further discussed in chapters five and six in the context of advancing a general theory of

[89] This critique in relation to Partch's system will be discussed in detail in chapter five in the context of advancing a general theory of microtonality.

perceptually-informed microtonality.

3.10 Johnston: Extended Just Intonation and Extended Notation

Ben Johnston (born 1926) is a composer who enjoyed direct contact with Partch's working methods, having privately studied with and assisted him in 1950, primarily helping with the tuning of Partch's instruments (Duckworth, 1995, pp.121, 133). Following this, Johnston began a career investigating the compositional possibilities of microtonal scales derived from *extended just intonation*: intervals generated from ratios beyond the 5–limit (Johnston, 1987, pp.517–8). However, two aspects of divergence from Partch's path are significant: (1) not being an instrument builder, as noted by Gann (1997, p.85), Johnston needed to develop a form of notation which conservatory-trained instrumentalists could understand; and (2) he had a more positive relationship and affinity with Western art music, resulting in his engagement with a variety of structures derived from this tradition (Johnston, 1984, pp.225–8). His extended version of standard Western notation, which initially assumes natural intervals based on a 5–limit just diatonic scale, enhances this with a variety of modifiers for different accidentals. This facilitates the notation of a range of microtonal intervals, extensible on the basis of using increasing prime-limit intervals as modifiers (Gilmore, 1995, pp.478–80; Fonville, 1991, pp.107–112; Gann, 1997, pp.86–7). The basis for this system of notation can be seen in the chart below (figure 25, next page):

raise	lower	ratio	cents
♯	♭	25/24	71
+	−	81/80	22
ㄥ	7	36/35	49
↑	↓	33/32	53
13	ƐƖ	65/64	27
17	ㄥƖ	51/50	34

Figure 25: Johnston's extended just intonation microtonal notation, from Gilmore (1995, p.480)

As can be seen from the chart, the system extends the gamut of intervals available based elaborations of the common practice notational approach to accidentals, with ‘standard’ sharps and flats rendered as 25/24 (71 cents) rather than standard 12TET semitones. This is extended through the use of a modifier for the syntonic comma, which is used to facilitate the tuning of microtonal 5–limit intervals; the arabic 7 provides a modifer for facilitating 7–limit intervals; 11–limit modifiers (33/32) are notated with an arrow. Higher prime limit modifiers are notated using the relevant arabic numerals. The notation system is extensible and currently accommodates primes of seventeen and nineteen, the latter intervals becoming relevant as Johnston extended his system of just intonation beyond his earlier limits (Gilmore, 1995, p.480). Thus, quite apart from Johnston’s pioneering role in the use of extended just intonation, his notation system provides a viable extension of standard Western notation and has frequently been used by his former student Kyle Gann as a preferred method of notating extended just intonation intervals (Gann, 2007).

3.11 Johnston's Compositional Philosophy and Conceptual Principles

Johnston's compositional approach, although indebted to Partch[90], was also quite different in some of its main preoccupations—crucially, for him, microtonal intervals are primarily a harmony–based issue:

> It [the deployment of microtonal intervals] is a harmonic matter. I hardly ever write music where you have melodic patterns unsupported. (Johnston, quoted in Duckworth, 1995, p.125)[91]

Furthermore, he has stated (presumably in indirect reference to Partch's more well-known preferences):

> The adoption of a microtonal ratio scale does not imply a return to modal monophony. Such a scale is equally applicable to harmonic polyphony. (Johnston, 1964, p.75)

Although Johnston spends much of this article discussing the description of formal connections between materials described numerically in terms of ratios (Johnston, 1964, pp.59–61,63–75), this representation is initially discussed (and justified) in terms of the sonority of the intervals based on periodicity and what he views as a general predisposition on the part of 'sensitive' performers towards the performance of

[90] Johnston himself has stated that his theoretical perspective derives approximately 50% of its material from Partch (Johnston, cited in Duckworth 1995, p.147).
[91] See also (Johnston 1964, p.60) for more detail on this point.

simultaneous sonorities in integer–ratio–based tunings (pp.59-61). In relation to the sensory aspect of consonance and dissonance, Johnston has stated:

> If you can't and don't respond honestly on a physical level to the actual nature of the sounds you're dealing with, then you haven't even put the first foot forward, you know. How are you going to walk? Above all, it's a sensory experience. And that entails a lot of other things. It involves the rest of our sensory experiences by association and, therefore, corporeality [...] Well, music has forgotten about that. But Harry's quite right.
>
> (Johnston, quoted in Duckworth, 1995, p.155).

Thus, this sensory aspect of consonance and dissonance for just intonation intervals is clearly seen by Johnston as a solution consistent with his predecessor's concept of corporeality. The focus upon interval ratios as the primary descriptor (and conceptual model) for pitch derives directly from Partch's breakthrough reassertion of the (Pythagorean) principle linking ratio and musical organisation (Johnston, cited in Gilmore 1995, pp.460, 500).

However, for Johnston, the sensory aspect of ratio–based sonorities is only a starting point. The ratio–based specifications of these sonorous relationships are discussed in terms of facilitating a formal and hierarchical structure, which Johnston viewed as the basis for musical listening (Gilmore, 1995, p.475). In introducing this idea, Johnston focusses on the relative merits of different types of conceptual models for describing pitch relationships. He notes the difference in conceptual priorities between linear melodic scales—equal temperament is described in these terms as a 'melodic equalisation of scale steps'—and the more conceptually rich harmonic ratio-based model, which is based on proportional relationships rather than step–wise subdivision (Johnston, 1964, pp.59–60). The proportional organisation gives rise to what he considers to be minor inequalities of interval size (at standard twelve–note scale divisions) which results but also results in greater clarity of consonance/dissonance distinctions (in terms of periodicity) in contrast to the 'blurring' inherent in equal temperament presentations (*ibid.,* p.60). Equal temperament is here described as a level of conceptualisation in musical organisation which simplifies relationships between pitches into a linear scale–based model; however, this simplification is considered by Johnston to be 'harmful' in its imprecision and comparative poverty as a conceptual (and relational) model for pitch (*ibid.,* pp.60–61). Thus, for Johnston, beyond the imprecision in the specification of the sonorous result (Partch's primary concern) lies the issue of conceptual imprecision.

Johnston began to compose with just intonation only in 1960 (ten years after serving his apprenticeship with Partch). It is frequently noted that in doing so he has deployed a number of organisational techniques or approaches which are derived from early to mid twentieth-century concert music: twelve–tone rows, neoclassicism, abstraction of popular/vernacular music elements (Gann, 1998, pp.85-86; Fonville, 1991, pp.120–121; Keislar, 1991, p.183). Johnston's String Quartet No. 2 (Johnston, 1964b)[92] typifies this approach and combines 5–limit just intonation microtonality with a structure based on permutations of twelve–note sets in a fifty–three–tone just intonation scale (Johnston, 1970). Since a just intonation system is being used, transposition of the sets implies shifting of intervallic relationships as the tuning of such relationships is governed by a

[92] Gilmore (1995, p.474) lists this as one of three key breakthrough works for Johnston.

limited scale, in effect redefining the twelve notes (pitch classes) as ‘twelve pitch catagories’ (i.e. an organisational level above individual tuning identity), allowing for a diversity of tunings drawn from the fifty–three–tone scale (Gilmore, 1995, p.479). Gilmore notes that this is an enharmonic scale described in Johnston (1964) which bases its structures on transpositions using 3/2 and 5/4 and 6/5 with each note derived from a nineteen tone just intonation enharmonic scale by having each interval act as major third, minor third, root and perfect fifth (through their deployment in triads), providing fifty–three–tone just intonation scale (Johnston, 1964 p.73; Gilmore, 1995, p.477–479). Johnston (1964, p.73) also provides rubrics highlighting scale patterns for what he terms ‘pitch regions’, which are recognised as being bordered by ratios of 3125/3072. The fifty–three tone–scale is set out in figure 26 (see following page).

1/1	C	125/96	E#	128/75	Bbb–
81/80	C+	320/243	F–	125/72	A#
128/125	Dbb–	4/3	F	225/128	A#+
25/24	C#	512/375	Gbb–	16/9	Bb–
135/128	C#+	25/18	F#	9/5	Bb
16/15	Db–	45/32	F#+	1875/1024	Ax+
27/25	Db	64/45	Gb–	**[50/27?]**[93]	B–
1125/1024	Cx+	36/25	Gb	15/8	B
10/9	D–	375/256	Fx+	243/128	B+
9/8	D	40/27	G–	48/25	Cb
729/640	D+	3/2	G	125/64	B#
144/125	Ebb	243/160	G+	160/81	C–
75/64	D#	192/125	Abb	2/1	C
32/27	Eb–	25/16	G#		
6/5	Eb	128/81	Ab–		
625/512	Dx	8/5	Ab		
100/81	E–	625/384	Gx		
5/4	E	400/243	A–		
81/64	E+	5/3	A		
32/25	Fb	27/16	A+		

Figure 26: Fifty-three tone enharmonic just intonation scale after Johnston (1964, p.73); altered specification for note B– *in bold, see note below*

[93] Johnston (1964, p.73) provides a ratio of 30/27, which is close to a Pythagorean minor third (32/27), and therefore diverges from the specification of adjacent intervals, which are in the region of a major 7th. A ratio of 50/27 (which is close in size to 15/8) would seem to be a more likely candidate for this scale position.

In terms of the structural deployment and effect of the microtonal materials in his String Quartet No. 2, Johnston notes in liner notes accompanying an early recording that:

> Listening to the quartet you will become aware of microtonally altered intervals and of *actual microtones*. These occur in the widely leaping melodic lines of the first movement, never in the harmony. The second movement has them in the harmony, sharply contrasting with the uncomplicated melodic lines and the harmonious consonances of the just intonation. In the last movement these altered intervals are set off by the clear consonances they surround. In the middle section they eclipse all other types of intervals, in a frenzy of contrapuntal activity. (Johnston, 1970)[94] [emphasis added]

In a sense, it could be argued that Johnston's use of just intonation parallels the somewhat paradoxical aspects of Partch's relationship with pure tunings. The concern for just intonation accuracy and extension of intervallic materials is only one of Johnston's structural concerns (just as, for Partch, conceptual rigour in the accurate rendering of intervals with pure tunings was not necessarily limited by the contextual demands of more monodic deployments).

Through his focus on these materials providing context–sensitive variations for the highlighting of differential perspectives on twelve pitch *regions* rather the standard monolithic 12TET divisions, Johnston is able to utilise these materials in a fruitful engagement with serial organisation. In doing so, his earlier work does not engage with just intonation intervals on the basis of more apparently obvious solutions deriving from the harmonic series as something of an elaboration of more traditional tonal structures

---

94 See also Gilmore (1995, p.475).

and combinations (an approach taken by other just intonation composers such as Partch and Tenney). Indeed, Johnston has discussed the dissolution of traditional triadic functional harmony, whilst noting also that *established* approaches to serial organisation point to a deployment which implies a significant diminution of pitch's previously–enjoyed primacy (Johnston, 1966, p.120). He traces this to what he viewed as Schoenberg's arbitrary acceptance of the limit in scale size of 12TET, which ‘committed music to the task of exhausting the remaining possibilities in a closed pitch system’ (Johnston,1967, quoted in Gilmore, 1995, p.473; Johnston, 1964. pp.60).

Johnston's initial solution, typified by the approach in his String Quartet No. 2, was the utilisation of an expanded range pitch identities (obtained through just intonation) for the rendering of twelve pitch *regions* organised on a serial basis (Johnston, 1966, pp.118–20). His intriguing rationale is that the just tuning of pitches is an important factor in adding perceptual distinctiveness to pitch materials in serial music through the context-sensitive rendering of twelve pitch regions, such as by the use of his fifty–three note enharmonic scale (*ibid.,* p.118). Thus, Johnston provides a revealing assessment of a possible relationship between serial organisation and proportional (including just intonation) organisation of materials:

> I believe that the above suggested methods supplement serial technique while neither denying its value nor interfering with its effectiveness nor functioning irrelevantly to it. I also believe that proportional organization can more easily do without serial organization than vice versa. (Johnston, 1966, p.120)

In keeping with this positive regard for a variety of formal organisational principles, Johnston's new vocabulary of materials is frequently deployed using syntaxes derived from previously established musical practice. The serialism-derived permutational approach for pitch materials is particularly significant alongside the integration of integer ratios as materials for note durations and tempi, in addition to tuning (Keislar, 1991, p.183). As noted above, microtonal intervals are used to highlight (and, present a new perspective on) more familiar sonorities. Although Johnston is happy to apply a range of organisational approaches which are not necessarily obviously implied by the use of just intonation, he believes that there is a structural and stylistic coherence to his usage, in contrast to the work of earlier generations of microtonalists:

> I don't like applying a nontraditional tuning system to a traditional style. What bothers me about the music of Alois Hába and Julián Carrillo is that the pieces don't seem unusual at all, *just the intonation*. The notes sound wrong, because the gestures, structures, and idioms are familiar from a different tuning. (Johnston, quoted in Keislar, 1991, p.23) [italics mine]

In an earlier statement, Johnston highlighs the importance of attention to tuning nuance in the performance of atonal music for (1) perceptual clarity[95] and (2) expressive purposes (Johnston, 1966, p.115). This clarifies the unusual relationship he maintains between what are commonly perceived as opposing poles of just-intonation-based harmony on the one hand and atonal forms of organisation on the other: Gann (1997, p.86) has succinctly described his primary compositional approach as 'well-tuned atonality', based on the aforementioned concern for perceptual clarity.

[95] This relates to the minimising of beating effects due to the use of intervals closer to just ratios. Further discussion of other aspects of perceptual clarity relating to the use of just intervals will be discussed in chapter five.

3.12 Pitch as Ratio: Perceptual and Functional Relationships

The immediate sensory perception of a dyad/triad/larger complex is not the sole arbiter of Johnston's structural conception of microtonal harmony. The directly *perceptual* relationship of pitches is seen as being extended by a higher–level (and hierarchical) cognitive/formal relationship. Fonville (1991, p.122) discerns in this higher–level structure a very direct influence derived from Partch: that of chord formations implied by the layout of his 11–limit tonality diamond. Fonville's analysis finds these influences in Johnston's String Quartets 5, 6, 7 and 9 (Fonville, 1991, pp.121–135). A particularly clear instance of this approach is the use of Partchian Otonal (i.e. derived from Otonality) and Utonal (from Utonality) hexads to generate tone-row material in String Quartet No. 6 (Fonville, 1991, p.125). Thus, the compositional approach clearly derives a significant degree of its macrostructure from the geometric representation that is the tonality diamond. That said, this structuring of pitch is not necessarily directly related to the experience of perception, especially when used in such a manner. Fonville (p.120) views the examination of Johnston's approach to structuring as a step towards an understanding of (tolerance) limits in the perception and reproduction (and, presumably, cognition) of microtonal materials, with what appears to be a tacit acceptance that such limits are not fully addressed by Johnston's theory.

Apart from the obvious impact of Harry Partch's work on Johnston's theoretical framework, his views on ratio–based organisation were further influenced by the theories of S.S. Stevens (of the Harvard Psycho–Acoustical Laboratory), which propose a ratio–based model for the development of more accurate psychophysical scales for certain percepts (Stevens, 1946; Stevens, 1957; Stevens and Galanter, 1957). The ideas elaborated in the earliest paper in this series, Stevens (1946), are cited in Johnston (1964, pp.57–8), a paper which could be regarded as the initial presentation of key tenets of Johnston's compositional philosophy. It is notable that Johnston's theories in this regard also seem to be quite consistent over time: as referenced earlier in this account, he stated as recently as 1995 that ratio–based organisation provides for a more sophisticated approach to the ordering of musical materials than the permutational ordering of a fixed number of scale steps through serial processes (Johnston, quoted in Duckworth, 1995, p.153). Therefore, an examination of the theoretical position presented in Johnston (1964) is proposed as an important basis for the assessment of the conceptual framework and approach which informs his microtonalism.

Johnston's (1964, p.57) theorising in relation to ratio–based musical materials was inspired by Stevens (1946, pp.479–480), who proposed ratio-based scales (derived from direct comparisons of two magnitudes of a physical phenomenon) rather than simple numeric scales (where physical attributes are assigned a value based on rank–ordering of magnitude estimations, calibrated to increments of discriminability) as the model which most closely corresponds to the perceptual scale structure. In effect, as Shepard (1981, p.29) puts it, this position 'claims that the power function rather than the logarithmic function is in fact the true psychophysical law' (i.e. corresponds most closely to perceptual scale structures for magnitude estimation comparisons for some simple physical phenomena).

Such a position would undoubtedly benefit proponents of just–intonation–based microtonality: interval ratios would be placed at the centre of a psychophysical model of perception, as opposed to the common musical model where (physically-based) ratios are less significant in the perceptual domain, ordering the psychological scale in a linear fashion based on increments of discriminability. However, a problem with Johnston's use of Stevens's theories arises from a discrimination which Stevens makes between physical phenomena which appear to engender a ratio–based scale in the psychological domain and those which facilitate simpler numerical ordering.

For Stevens, the validity of the ratio–based scale model is based on perceptual continua for which ratios of magnitude estimation are non–linearly related to steps based on discriminability of difference; hence the ratio model allows for more accuracy in setting scale steps than a model based on multiples of minimum intervals of discriminability which are variable with respect to a magnitude scale throughout its range (Stevens 1957, p.154) The ratio–based psychophysical scales (termed *Class I* or *prothetic* continua; e.g. loudness)—scales which are related by Stevens more directly to magnitude estimations, with equal ratios between successive intervals—are contrasted with those for which a simple numerical figure for rank is based on what are considered to be rougher magnitude estimations which simply reference multiples of *discriminability* increments of magnitude changes (Stevens and Galantner, 1957, pp.377–8, 400–401, 409). In the case of pitch, Stevens (1957, p.154) classes it as a *Class II* or *metathetic* perceptual continuum which is linearly related[96] to a scale based on steps of discriminability with respect to changes in frequency (*ibid.,* p.155).

---

[96] In the middle of the more commonly-used musical frequency range (Stevens and Galantner, 1957, p.408).

With reference to an environmentally–based explanation for the distinction between the two scale types, Stevens and Galantner (1957, pp.401,406) describe *methathetic continua* (such as pitch) as being based on position (referencing the place-based mechanism of inner ear registration of pitch) rather than magnitude and regard such scales as less important in evolutionary terms, resulting in a psychophysical perceptual mechanism/process which is effectively less quantitative and reliable:

> A defensible view is that what we have called magnitude scales on Class II continua are never more than interval scales, and that ratio scales are possible only on continua of Class I. Perhaps we ought not to use the term magnitude for subjective scales on Class II continua, but an alternative term has not suggested itself. (*ibid.*, p.406)

Thus, pitch changes (scale steps) which are related to fixed multiples of the discrimination limit (which are termed category ratings) are considered in Stevens's theoretical framework to be psychologically represented by approximations of simple linear numerical estimate of magnitude ranking and not directly represented as ratios (*ibid.*, pp.401, 406). As such, this research, alongside previous work by Stevens (Stevens and Volkmann, 1940, p.353) regarding the development of a metathetic psychophysical scale (the *mel* scale[97]) for relating frequency to pitch, provides no *direct* basis for the use of ratio-based scales for pitch. In this particular regard, Johnston's advocacy of ratio-based pitch scales on the basis of the theories of Stevens appears questionable.

However, Johnston's advocacy of ratio representation as perceptually grounded is

---

[97] Pitch perception and psychophysics is discussed further in chapter five.

helped by a modification of this model, which is advanced by Stevens and Galantner (1957, p.406) to the effect that interval scales may be transformed into ratio representation with respect to fixed 'end points' and 'distances' along the psychological continuum can be related in terms of a ratio scale. They note that *comparisons* between intervals (differences) may be regarded as ratios, allowing experimental subjects to make more direct estimations of pitch magnitude (*ibid.,* p.406). In effect, such a view suggests that a dual model might be applicable to psychophysical scale construction of interval discrimination and ratio-based comparison for pitches (Elmasian and Birnbaum, 1984, p.531). With regard to pitch and direct magnitude estimation, Stevens and Galantner found their psychophysical mel scale for pitch to be linearly related to magnitude estimations as well as category judgements (salient scale steps) and/or steps based on multiples of the minimum discrimination increment; more specifically, the magnitude estimation (ratio–based) scale lay between two previously posited mel scales, with category judgements linear within the more common musical pitch range, i.e. below 4,000 Hz, with another exception for low frequencies below 200 Hz (Stevens and Galantner, 1957, pp.406–9).

To ascertain whether ratiobased comparisons do indeed play a role, Elmasian and Birnbaum (1984, p.531) experimentally investigated the possibility that such agreements between the mel scale and discriminability–based differences or magnitude–based estimations occurs because both operations are used with respect to the psychophysical 'parsing' of frequency information as pitch. However, although their results found differences between magnitudes for ratio–based and difference–based/category–based (i.e. subtractive) comparisons, they found no significant difference between magnitude *rank orders* based on ratio judgements or category differences (i.e. more commonplace linear scale representations); some differences between rank orders would have been expected if two operations from these different models played significantly distinct perceptual roles (*ibid.,*pp.535–6). Following this, an analysis on the basis of a rationalisation of these two possible methods of representation is provided, resulting in a conclusion that the difference–based/category–based subtractive model is to be preferred (*ibid.,* p.536). This, they note, has the benefit of agreeing with the most common conceptualisation model of pitch/frequency within music, the logarithmic scale, whereby transpositions of materials maintain constant subjective distances between notes rather than distorting their relationships, as would be the case if magnitude estimations were directly related to ratios on a linear frequency space (Attneave and Olson, 1971, cited in Elmasian and Birnbaum, 1984, p.536).

Therefore, based on the psychological research, there seems to be little advantage incurred by the use of a ratio–based model instead of (or in addition to) the more standard model for pitch scales. As such, there is little support from this quarter for Johnston's placement of ratios at the heart of a perceptual model for music. However, this is not to imply that his use of ratios is completely superfluous and lacks any utility in terms of the creative processes involved in conceptualising and analysing musical structuring. As discussed in relation to Partch, ratio representation provides a degree of insight into the resulting sonority of a simultaneous pair of intervals through periodicity–based consonance and dissonance and the interaction of harmonic components, a quasi–timbral aspect to harmony: Johnston himself focusses on a periodicity–based aspect in some parts of his account (Johnston, 1964, p.58).[98] In other

[98] See also Kirck (1987) for a discussion of Johnston's extended just intonation and periodicity-based

cases, Johnston elaborates upon this model to focus on functional relationships derived from ratios which are taken to permit minor distortions of strict ratio relationships:

> So long as music is designed by principles based upon ratio–scale order, distortion of its pitch proportions, whether by equal-temperament or simply by imperfect performance, does not destroy its psychological effect of 'progression' and change. (*ibid.*, p.74).[99]

As can be seen from many of the intervals in Partch's 'One–footed Bride' (though he did not discuss it extensively) and as also discussed in Wishart (1996, pp.71–75), small changes in pitch may result similar consonance/dissonance judgements, even if the resulting ratios produce significantly different periods. This might be viewed as relating to the tolerance of minor distortions of interval ratio relationships. Thus, for Johnston the ratio model does have a certain utility in the assessment of two different aspects of consonance and dissonance: the sensory attributes and functional relationships.

Johnston's invocation of the ratio basis for the description of certain relationships in tonal harmony (Johnston, 1964, p.75) is reasonable, based on an analogical use of Stevens's theories of scale types as applied to musical organisation: melody being treated as a simple linear ordering of pitch–space, with ratio describing functional relationships in harmony. As he describes it in an earlier passage, 'the harmonic use of pitch (carefully tuned simultaneous pitch combinations) is an example of ratio scale ordering' (*ibid.,* p.57). Indeed, in a broader context, his subsequent elaboration regarding distinct functional roles for intervals organised by ratio–based classifications

---

organisation in the context of computer music.

99 This idea of permissible distortions within ratio-based 'categories' is discussed further in the next chapter in relation to Tenney.

is intriguing and provides some further justification for the use of ratio–based conceptualisation within his music theory. Like Partch (1974, p.126) he is interested in the implications of incorporating higher prime factors as materials for interval ratios, thus providing a more explicit engagement with ideas regarding functional relationships and distinctions between them (Johnston, 1964, p.74). He posits a variety of functions categorised by successive prime limits, with one contributing unity/identity, two contributing ‘recurrence or repetition’, three to two contributing ‘polarity’ and five contributing to a sense of distinctiveness in tonality through major/minor modal identity or ‘coloration’ (*ibid.,* p.74). By inductive reasoning, Johnston asserts that other prime numbers may also contribute to similar functional distinctions. He also cites the example of seven-based intervals which he argues, contribute to ‘centralized instability, suspending the dominant–tonic(3 to 2) polarity’, in addition to a consonant tritone (7/5) and consonant minor seventh (7/4), in addition to a consonant minor second (8/7).

However, the description ‘centralized instability’ is perhaps a little ambiguous and does not, to my mind, sufficiently describe the functional roles of the various intervals. Perhaps a more appropriate description is that the seven–based intervals provide novel imperfect consonances which attenuate or suspend the dominant–tonic polarity (this seems to be already implied in his invocation of a consonant use of the dominant seventh chord as inspiration). One further (more general) insight which informs Johnston's (Stevens–derived) theoretical framework is the comparison of standard musical scales (linear pitch scales, termed ‘interval–scales’) and ratio-based scales regarding their respective symmetrical and asymmetrical structures and resultant functional properties (Johnston 1964, p.74). He further notes that interval–based scale design ‘emphasises symmetry’ and may facilitate tonal ambiguity through its grid-based equality of steps whereas ratio-based scales can emphasise hierarchical relationships which are reflected in functional relationships in progressions. In this regard, he asserts that even the ‘distortion of pitch proportions’ of equal temperament (or imperfect intonation in performances) does not negate the psychological (functional) imperative of ‘progression’, though he does not specify the degree of tolerance/accuracy for which this may be valid (*ibid.,* p.74).

To conclude this discussion of Johnston’s response to Stevens’s theories, if the ratio model is indeed a useful musical model it is because Johnston's incorporation of ratio-based scale ideas has relevance and merit for reasons other than those originally proposed by Stevens. Rather than having merit as a psychophysical scale (i.e. in the more ‘immediate’ perceptual domain), the use of a ratio model is more relevant in the context of a theory of a description of more complex functional relationships, i.e. it provides a model for possible cognitive relationships between pitch materials. Furthermore, Johnston's application of the ratio model to the description of functional relationships is on the basis of a sophisticated refinement which incorporates the concept of tolerance of minor deviations from the prototypical instance defined by strict integer ratios, prioritising the functional over the sensory to some degree (i.e. in the acceptance of some degree of approximation and functional equivalence instead of conformity to precise specification of intervals with particular composite periodicities and, hence, sensory–based definitions). For Johnston, the most important use of integer ratio scales is thus arguably in the specification of novel scale structures (within these bounds) rather than being as concerned with strict intonational accuracy, as Partch was. Based on such an analysis, my conclusion is that for the harmonically–minded just intonation microtonalist, Johnston’s approach to ratio representations clearly provide a beneficial but provisional and incomplete framework for the structuring of relationships between pitches primarily with a view to providing an insight into possible functional connections.

3.13 Johnston's Multidimensional Functional Models

Regarding a broader aspect of Johnston's ratio–based structural (i.e. functional) conception, Gilmore (1995, p. 481) notes that an important development is to be found in its extension into multidimensional lattice structures. These structures extend Partch's two–dimensional tonality diamond idea into a multidimensional space, allowing for the versatile representation of tuning systems based on the organisational principle of an extra dimension per prime limit.[100] In this model, two dimensions are provided for 3–limit Pythagorean scales (based on 2/1 and 3/2 relationships in their construction), three dimensions for 5–limit just intonation etc., providing a geometric arrangement of pitches (nodal points) whose connections across the various dimensional axes provide a description of possible functional relationships between these novel pitch materials (*ibid.*, pp. 481–3). An example of a multidimensional lattice to describe functional pitch relationships can be seen on the following page (figure 27, following page):

[100] According to Gilmore (1995, p.481), Johnston was influenced in this regard by a relatively cursory familiarity with the writings of Fokker.

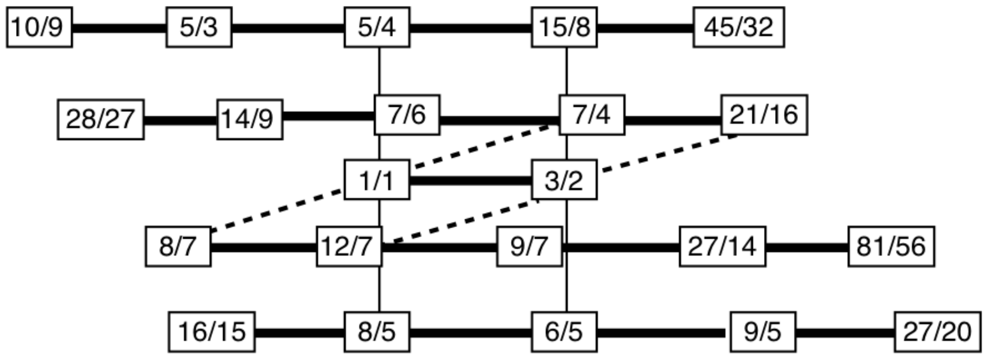


Figure 27: A three-dimensional lattice featuring Johnston's pitch-space for his String Quartet No. 4, transposed within a single octave, after Gilmore (1995, p.482)

Fifth-based (3/2) relationships indicated by thicker horizontal lines, third-based (5/4) relationships indicated by thin vertical lines; Harmonic seventh relationships (7/4) indicated by dotted diagonal lines to denote third dimension. In this case, the number of dimensions required is reduced by one since relationships are only provided within a single octave, hence the 2/1 dimension is eschewed.

The genesis and application of this type of model is discussed in detail in detail by Gilmore (1995, pp.477–483) in an account which focusses primarily on pitch-space models based on geometric representations from Partch through Johnston to Tenney. As discussed in relation to Partch, geometric representations of pitch-space may provide an insight into periodicity–based consonance/dissonance judgements (useful if periodicity is indeed a salient factor in such judgements) but the graphing of this attribute is not expressly embedded in their structure. Therefore, it is not a model which prioritises the representation of consonance/dissonance, but rather the representation of possible formal connections between intervals and functional attributes of these connections. In addition, although Johnston, as discussed above, has previously noted that tolerance ranges for tuning deviation are a factor in the perception and processing of such materials, this aspect is not addressed explicitly in his multidimensional pitch–space models. Thus, a proliferation of dimensions in this model is not limited by a tolerance principle whereby minor deviations from the canonical specification are treated as functionally identical; the only limitation is with how many prime–based dimensions are deployed.

In one sense, this is a fruitful position for a structural descriptor of microtonal music to take: it allows for the description of a large number of distinct categories of microtonal materials based on the numerical distinctions inherent in their ratios. On the other hand, it does not take account of any perceptual (or cognitive) limitations on the number of distinct intervals which a listener can perceive and compare.[101] My own assessment is that such a geometric mapping of these relationships certainly provides an important *compositional* aid in terms of providing a model of formal structuring. The addition of an extra dimension per prime limit embeds Johnston's presumption of formal attributes common to intervals based on different prime factors (3–limit establishing broad tonic/dominant relationships, 5–limit establishing major/minor tonality distinctions, 7–limit providing an alternative pole to moderate the dominant/tonic centres of activity).[102]

---

[101] A more explicit treatment of the implications of such limits and a revised model which incorporates an assumption of some degree of functional approximation of intervals is provided in Tenney (1983), discussed in detail in the next chapter.

[102] It should be noted that Fokker (1955) separately outlined a three-dimensional representation of pitch-space through his advocacy of *lattice diagrams* which can encompass the seventh harmonic as a

Although Johnston has not provided explicit theoretical accounts regarding the functional distinctions provided by further prime limits, harmonic series intervals based on these primes include the 11th harmonic as harmonic tritone (11/8 or 551.318 cents), the 13th harmonic as a harmonic major sixth (13/8 or 840.528 cents), which could be seen in the context of his description for 7–limit, as providing alternative functional 'gravitational' poles for the suspension of traditional tonic/dominant relationships. A more interesting possibility in the context of a unification of chromatic (in the sense of small–division stepwise movement) and harmonic practice is the 17th harmonic (17/16 or 104.955 cents), which differs in size by less than 5 cents (negligible in melodic terms) from the 12TET semitone. Interestingly, none of these functional archetypes are expressly microtonal (though the 7/4 'minor seventh' and 11/8 'tritone' are microtonally distinct from their lower prime-limit 'prototypes' in 5–limit just intonation or its 12TET derivative, though such distinctions might be better considered as xenharmonic). However, a small number of 'modulations' by such intervals (or more traditional lower prime-limit intervals) or the deployment of these xenharmonic interval variations alongside more standard versions does introduce microtonal intervals. Indeed, such a focus on a scale-based analysis or taxonomy of intervals is arguably to miss the point of Johnston's theoretical model: his preferred conceptual mode transcends scale-based microtonal/'macrotonal' distinctions in favour of proportional descriptions in a functional harmonic context. Thus, for Johnston, microtonal intervals are something of a by–product of his functional conception. The resulting intervals may be microtonal, but they are the product of a macrostructural elaboration of the traditional functional model of harmonic relations.

---

functional consonance—see previous discussion of Fokker in relation to 31TET in chapter two.

Johnston's descriptive model is undoubtedly a fruitful model in terms of its generative and analytical applications. However, it is still based on the assumption that the cognitive organisation of these numerically distinct materials partly or largely matches this formal structure. The degree to which the cognitive ordering of these materials follows an unmediated ratio–based structure is open to question, as is the degree to which the materials so derived are all perceptually distinct. Certainly, many subsequent microtonal just intonation composers (such as Tenney) have sometimes focussed on a very particular organisational style which emphasises the sonority aspect of microtonal combinations through comparatively slow–moving harmonic progressions.derived from the harmonic series[103], or have proposed that some sort of perceptual or cognitive limiting factor exists whereby the proliferation of extra dimensions in this model of functional pitch relationships is halted.[104]

3.14 Conclusion

Partch and Johnston are the exemplar–pioneers of twentieth–century American just intonation microtonality, providing theoretical perspectives with a significant degree of unity regarding the use of such materials. Their application of frequency ratios, not only to the specification of notes in scale construction, but also to the description of functional potentials through graphical models is their most significant shared development.

---

103 Although Johnston has sometimes deployed materials in harmonic series configurations, such as in his String Quartet No.9 (Johnston, 1987); see Gilmore (1995, p.487) for a brief discussion of this aspect.
104 This topic will be discussed further in the section on Tenney in the next chapter.

Johnston's (1964) contribution, based on the theories of Stevens (1946), attempted to go even further, placing the ratio–based representation of pitch–frequency at the centre of a perceptual model (in addition to its secondary usage in specifying formal connections between pitch materials), although the application of these ideas from Stevens are not actually consistent with the original research.[105] Of more lasting significance, however, is Johnston's elaboration of Partch's original graphical and functional insights into a multidimensional lattice–based pitch space, which would prove particularly influential on the theoretical work of James Tenney (see further discussion in the next chapter).

In relation to Partch's contribution, it should be stressed that some aspects of his earlier work remain the more psychologically sophisticated, including his lack of sole reliance on a numerical/spatial model of relationships between notes, demonstrated by the addition of his empirically–based 'One–footed Bride' representation of the relative sensory consonance/dissonance of dyads to the numerical/spatial tonality diamond.

Finally, in more general terms, the examples set by Partch and Jonston in the performance of music with microtonal intervals provide significant steps in the demonstration of the perceptibility and performability of these materials. As mentioned at the start of this chapter, significant figures from later generations of American composers, such as Lou Harrison, James Tenney, La Monte Young, Terry Riley and Glenn Branca have chosen to work within this field of microtonal just intonation. In

[105] However, as noted above, this does not necessarily undermine the creative appropriation of such ideas in an analogical mode as an aid to formal compositional structuring, as opposed to the description of the nature of the psychophysical scale of pitch.

relation to the question of influence, Partch's concern for the consistency of his philosophical–aesthetic position finds a parallel in the rigorous theorising of Tenney and the perceptually–grounded conceptualism of both Tenney and Young (the subjects of the next chapter). His rigorous and structured autodidactic engagement with the issues inherent in creating new and adapted instruments and the development of related performance practices prefigures the much later work of Glenn Branca; see (Gagne, 1990; Gagne, 1993; Gann, 1997; Bridges, 2003). However, beyond these more practical aspects of influence, the influence of Partch's perceptually–aware theoretical work on the subsequent literature remains particularly notable (Sethares, 1999; Benson, 2006), thus allowing his ideas to form a basis for the work of later generations in a manner which is 'aesthetically neutral' (Tenney, 1983, p.15) and, hence, broadly applicable.

3.15 Chapter Summary

This chapter has examined the theories and practices of twentieth–century American just intonation pionereers Harry Partch and Ben Johnston. The influence of Partch, in particular, on subsequent literature is noted, in addition to the manner in which his approach offers an iconoclastic break from many core structural assumptions of Western common practice music[106] (in contrast to its grounding in earlier, particularly non–Western music theories and approaches). The ratio–based conception of musical structure shared by both composers is investigated, with a particular focus on their treatment of formal/functional and perceptual/sensory relationships between microtonal intervals, interrogating their theories from the perspective of psychophysics (whose

[106] With a particular focus on his espousal of alternatives to the codified functional harmony system based on a closed 12TET scale structure.

early models both composers engaged with in their theorising). The spatial representation of formal/generative connections between extended just intonation materials is highlighted as the clearest element of common ground between these two composers and its utility as a model in relation to perceptual experience is discussed. However, Partch's more empirically–based graph of comparative consonance and dissonance is highlighted as particularly significant for its consistency with later experimental findings and as illustrating a potential modality by which microtonal intervals may be delineated or grouped on the basis of perceptual distinctiveness or similarity.

Chapter 4: Just Intonation Microtonality II: the Perceptual-Conceptual/Ecological Approaches of La Monte Young and James Tenney

This chapter will discuss the work of a later generation of microtonalists, La Monte Young and James Tenney, whose work is also based on the specification of materials using just intonation. In particular, it will examine how their experimentalist approaches can be related to novel ecologically–based conceptions of musical structure which enjoy significant compatability with psychological models.

4.1 Experimentalism and Perceptual–Conceptualism

The innovation in just–intonation–based musical materials signalled by Partch's work was but one instance of a cycle of philosophical debates and aesthetic revolutions which were gripping American (and, indeed, global) composition during the middle of the twentieth century. Ben Johnston's time with Partch (in 1950) occurred at the start of a decade which saw a fertile period of musical experimentation which included Cage's adoption of chance procedures in 1951[107], followed in 1952 by his *4'33",* with the establishment by Vladimir Ussachevsky of an electronic music studio at Columbia University beginning in 1951, later to be expanded as the Columbia-Princeton Electronic Music Centre in 1957/8 (Holmes, 2008, pp.93–5, 104). One of the by–products of this general milieu of experimentalism was the development of an experimental music scene in New York City which was stimulated both by Cage's influence—through his teaching at the New School for Social Research, his classes being attended by many of the members of the early Fluxus movement (Nyman,

---

[107] In *Imaginary Landscapes No. 4* for 12 radios and *Music of Changes* for piano, see (Gann 1997, p.135).

1974/1999, p.13, 51,75)—and the burgeoning Downtown New York scene of loft–dwelling artists; see Zuckin (1982, pp.431–2). Indeed, so far-reaching was Cage's influence upon this scene that Gann (1997, pp.154–5) has grouped much of the resulting practice under the heading of 'Post-Cage Conceptualism'.

La Monte Young (b. 1935), a key figure of this early scene, traversed the boundaries between these more experimental creative practices and musical minimalism (Gann, 1997, pp.187–8) and emerged into a fruitful countercultural milieu when he arrived to study in New York at the New School in 1960. With the coming of the sixties, a new musical movement developed from Fluxus in the lofts of downtown Manhattan and central to this was a pioneering concert series by La Monte Young and Richard Maxfield at Yoko Ono's loft in 1961 (Gann, 1997, p.155).[108] The resulting art events or artefacts of this early Downtown New York scene represented a type of conceptually-driven practice which problematised many previously-held assumptions about musical organisation and experience. The loft–based performances which developed in response to Cage's creative provocation (in addition to the changing socio-economic conditions which facilitated the development of new venues) provided an alternative to the university-based venues and concert halls, facilitating performances which challenged the traditional boundaries of performance spaces, the nature of social interactions in performance and extremes of performance conditions such as long durations and the use of amplification. As Young's music developed further in the direction of amplified drone-based presentation, xenharmonic renderings of more familiar intervals and expressly microtonal materials became the increasing focus of his

[108] See also Flynt (1996, pp.79–81) for Young's early relationship with Fluxus.

compositional practice. In effect, for Young the more general experimentalism of the earlier 1960s solidified as a more singular avenue of compositional research into drone-based microtonality in the late 1960s.

James Tenney (1934–2006) is also treated by Gann (1996, pp.167–9) as an exponent of 'Post-Cage Conceptualism' and occupied a variety of roles associated with musical experimentalism throughout his life. These included time as a researcher into computer music (at Bell labs, where he was involved in the early development of the Music N synthesis language[109]), in addition to a formative engagement with the New York Downtown scene (where he performed in the ensembles of Reich and Glass and founded his own performance group) and, most significantly a long career primarily spent as an instrumental composer and influential music theorist. However, Gann's rubric, in the context of conceptualism relating to perceptual issues, provides a key insight into the ostensibly disparate professional roles which Tenney occupied throughout his life. From this perspective, his career could be viewed instead as a unified and extended programme of composition–as–research, an investigation of some of the perceptual phenomena which underpin more experimental composition[110] and the development of creative and theoretical responses to the results of these investigations. Of the perceptual phenomena which he investigated, the harmonic series, came to be one of his major preoccupations from 1972 onwards (Tenney, cited in Gagne, 1993, p.393), although he also proposed a more general analysis of perceptual grouping and segregation in music derived from Gestalt psychology theories in his master's thesis,

[109] See Tenney (1969) for detailed discussion of this period.
[110] Wannamaker (2008, p.123) describes a 'quasi-empiricist musical aesthetic inherited principally from John Cage' which he discerns in the approach of Tenney and many of his contemporaries.

later published as *Meta/Hodos* (Tenney, 1964/1986). Thus, like Young, Tenney underwent an early period of pluralistic experimentation which informed a later period of engagement with microtonal materials and their formal implications.

For both Young and Tenney, two aspects of the 1960s milieu of experimentalism allowed them to create music which was revolutionary in its choice and treatment of microtonal materials. The pervasive influence of Cageian experimentalism and conceptualism was combined with what might be viewed as related currents of theoretical research and exploratory practice in new fora from the research lab to the loft–based performance. Questions which had not previously been asked about the nature of and relationships between musical materials (and their contexts) were being asked by researchers (sometimes also composers) in the burgeoning fields of auditory perception and audio/computer music research, at the same time as composers instigated a revolution in the creative use of musical parameters, materials and contexts. For both Young and Tenney, their engagement with conceptualism was informed by a 'perceptualism' as they sought to explain the novel perceptual results of their experimental (and parametric–focussed) musical practices. The singular conceptualism of Young's *Compositions 1960* series led to the *perceptual–conceptualism* of his early drone-based pieces as they reconfigured listener expectations through experiencing extremes of musical materials (in the domains of duration, amplification and microtonality) whose novel perceptual results contradicted common–sense predictions, casting new light back on the compositional 'question'. Tenney's engagement with perceptual phenomena predated his time at Bell Labs (his master's thesis had engaged in theorising informed by Gestalt psychology). However, it was at Bell Labs that he engaged in research into the perception of timbre, alongside the creation of a number of computer music pieces and ‘a curious history of renunciations of one after another of the traditional attitudes about music, due primarily to a gradually more thorough assimilation of the insights of John Cage’ (Tenney, 1969, p.2). As such, Tenney’s more formal research into the parameters which contribute to musical timbre contributed to his own development of a post–Cageian conceptual framework which encompassed an expanded view of novel possibilities in musical materials and structuring and led to a series of compositions which investigated these possibilities, including a significant strand which investigated microtonality. Thus, Young and Tenney both enjoyed a fruitful relationship with post-Cageian musical conceptualism which informed pieces in their application of this conceptualism to rigorous compositional explorations of unusual perceptual cases in music. I have chosen to term this approach *perceptual–conceptualism* (or, perhaps, *perceptualism*, to coin a neologistic shorthand).

4.2 Young’s Perceptual–Conceptualism

Young's *Composition 1960 #7* is a key early case of his perceptual–conceptualism, instructing a performer to simply sustain a perfect fifth for ‘a long time’, with the conceptually–based performance instructions yielding unexpected perceptual results. The conceptual importance of the drone as a distinct category of musical materials and their structuring is arguably subsidiary to the actual experience of the perceptual implications of this apparently straightforward (if somewhat extreme) case in musical perception. This is because the perception, on extended listening, is not that of a single, fully coherent source, but rather a multiplicity of drones (perceptually segregated harmonic partials) deriving from a single source. The most prominent cause of the perceptual segregation/decomposition of the higher harmonic partials is the instability in relative tunings which cause certain partials of the component tones which are relatively close in frequency to interact with each other at varying rates, causing the phenomenon known as *beating* (slow amplitude modulation at a frequency equal to the frequency difference between the two tones). The resulting auditory 'scene' is therefore quite dynamic and results in the materials conspiring with the mind's 'rules of thumb' (or, more formally, *heuristic* processes) for auditory perception to begin to decompose the drone in the listener's perception, related to a basic principle discovered by Helmholtz in 1859 and reprised in Bregman (1990, pp.220–4) as the *old–plus–new heuristic* in auditory parsing processes for grouping/segregation.[111] In this case, an increasing segregation of harmonic components happens as the minor variations in amplitude and frequency produce *false positives* indicating new auditory 'objects'. Although one of Young's earliest mature compositions, this piece anticipates (or represents) a fruitful cross–fertilisation of his conceptual interests and his engagement with novel sensory experience. Crucially, it acts as a reminder that duration of a stimulus can affect the perception of a given sonority, sometimes in very unexpected ways.

Young's first original experimental music intuition, the investigation of long durations[112], led to the development of an interest in tuning (as long durations allow for the periodicity of a given sonority to become more clearly apparent), resulting in his later career being devoted to the development and use of a system of extended just intonation. As noted above, drone-based presentations (using harmonic timbres)

[111] Further details relating to the implications for microtonal music of Bregman's research will be presented in chapters five and six.
[112] See also his *Trio for Strings* (1958) as the earliest example of music of his music of long durations (Gann 1997, p.188)

facilitate the perception of segregated harmonic partials. These cases thus resulted in the increasing perceptibility of harmonic series intervals, which encouraged their use as primary musical materials/intervals. A performance practice and a performing group, the Theatre of Eternal Music, began to coalesce around Young. They performed largely drone–based music (initially to provide a fairly static accompaniment for his saxophone playing), though the implications of such presentations regarding the increase in audibility of upper harmonic partials began to be noted and utilised intentionally for such purposes. Tony Conrad (born 1940), another member of the group's early incarnation, who was both a violinist and mathematics graduate, pointed out the relationship between whole number ratios and consonances which was present in the harmonic series, leading to Young's use of harmonic number notation (which denoted implied microtonal intervals) for a rule–based improvisation, *The Pre-Tortoise Dream Music* (Young, 1964)*;* see Gann (1997, p.189).

A debate surrounding the authorship and creative credit within the Theatre of Eternal Music has taken place in recent years, with disagreements between the account of Young and his wife Marian Zazeela on the one hand (who assert that Young was the sole composer) and early group members Tony Conrad and John Cale on the other.[113] Conrad and Cale assert that the pieces performed by the group were the product of a novel collaborative form of composition. This debate is discussed further in Gann (1996) and Bridges (2003, 2008) and Joseph (2008, pp.26–40, 72–4, 140–1), the latter covering the debate in the context of Conrad's career. Gann highlights the aspects of

[113] Both Conrad and Cale had established significant compositional credentials in their own right by this time; see Joseph (2008) and Cale and Bockris (2000) for further details regarding their previous activities.

precursory activity and continuity in Young's practice and, whilst not making a final judgement regarding the ‘legal distinctions’ of authorship, he nonetheless proceeds based on the assumption that Young is the sole author of the Theatre of Eternal Music pieces (Gann, 1996, p.161). My own position has been formulated in my MPhil thesis (Bridges, 2003) and subsequent article (Bridges, 2008, pp.9–15). These compile a number of pieces of information which suggest that Conrad[114] and Cale at the very least exerted a significant (indeed, essential) formative influence on the musical approach of the group (through the introduction of tuning theory and amplification), whilst noting that some of the arguments presented by Young himself (Young, 2000, pp.1–25) form a coherent case in relation to more traditional conceptions of authorship and musical copyright. (In addition, some of the structural and aesthetic precursors to the Theatre of Eternal Music pieces in Young’s own (separate) work are also highlighted.) I also note Conrad's assertion that the challenging of traditional/historical conceptions of authorship is one of the group's most significant contributions (Conrad, 2007). In this regard, Joseph (2008, p.37) suggests that the disagreement between Young and Conrad (the most voluble actors in this dispute) is not simply based on ‘differences of opinion’ but more fundamentally grounded in ‘opinions which are different *in kind*, situating themselves on opposite sides of a whole series of interrelated questions of authorship, history, the institution and, ultimately, power.’

[114] Declaration of interest: I studied aspects of microtonal structuring, perception and practice with Conrad in January 2006, though I had already formulated ideas relating to the Theatre of Eternal Music authorship issue in 2003 during the completion of my MPhil research.

4.3 The Harmonic Series as Formal Structure in Young's Work

The focus on perceptual phenomena engendered by the use of long durations marks out the work of Young's early ensemble and his own later compositions (in the form of instrumental/acoustic performance and sound installations) as having a thorough–going concern for the creative implications of the fundamentally changed perceptual experience of using microtonal materials.[115] Young's first explicit deployment of the harmonic series as compositional structure is traceable to February 1964. The aforementioned *Pre-Tortoise Dream Music*[116] (Young, 1964) was a rule–based improvisation comprising harmonic series melodies in each part based on a loose progression through the list of notated harmonic numbers (Gann 1996, p.157). The fairly slow–moving free rhythms of the parts, combined with the harmonic tunings of the elements, leads to the impression of a largely unified (and immersive) harmonic drone with occasional novel (and somewhat dissonant) intervals heard as 31st and 63rd harmonics are introduced. The harmonic numbers along with the (more familiar) frequency ratios below are from Gann (1996, p.158). The harmonic numbers in Young's music are calculated on the basis of a low fundamental frequency which is not sounded directly; indeed, in many early Young works the 'fundamental' is subsonic and intervals are sounded against an 120 Hz drone derived initially from the motor of an aquarium which Young kept pet turtles in, which had the benefit of allowing the pitches used in the music to be 'in tune with the frequency of the 60 Hz AC power supplied by Con Edison [...] the power line drone of the American continents' (Young, 2000, p.14). For the present purposes, the frequency ratio illustrates the pitches as used within an octave

---

115 In the context of drone-based presentation.

116 Gann (1995, p.158) notes that this was retroactively titled as a precursor to Young's later series of drone-based ompositions, *The Tortoise, His Dreams and Journeys.*

span (see figure 28, below):

Harmonic no:	**32**	**48**	**56**	**64**	**63**	**56**	**63**	**62**	**63**	**56**
Ratio:	**1/1**	**3/2**	**7/4**	**2/1**	**63/32**	**7/4**	**63/32**	**31/16**	**63/32**	**7/4**
Harmonic no:	**42**	**56**	**63**	**42**	**28**					
Ratio:	**21/16**	**7/4**	**63/32**	**21/16**	**7/8**					

Figure 28: Progression of harmonic series intervals in The Pre-Tortoise Dream Music*, after Gann (1996, p.158)*

It is notable that Young's interval structures owe everything to the *direc*t application of harmonic series structures, rather than any secondarily derived intervals (such as those from Partch's *utonality*)—the 21/16 approximation of a perfect fourth is preferred over the 4/3 which does not directly occur within the harmonic series (Gann 1996, p.159). As Gann notes, the structure of the piece is based on an exploration of the pitches in the context of 'feeling the tuning of each new note', establishing familiar intervals such as the tonic, dominant and seventh harmonic (7/4) before using these as stepping stones to more unfamiliar/remote intervals such as the 31st and 63rd harmonics (the eponymous 'outer edge' consonances from the title of Gann's article, 'The Outer Edge of Consonance.' Gann also notes that in the extant recording, the seventh harmonic is emphasised/tonicised through the sounding of a drone which highlights the simple relationships with the 7/4 which the intervals 21/16 (3/2 or perfect fifth above 7/4), 63/32 (9/8 or major second above 7/4) possess. Thus, the drone-based use of harmonic series structures embodies an elegantly simple approach to the mapping of the piece's pitch–space (see figure 29, next page). Note that unlike Johnston's pitch–space model, Young’s model embraces an approach derived directly from relatively simple transpositions within a primarily 7–limit framework, with the somewhat isolated presence of the 31st harmonic highlighting the difference of Young’s approach from Johnston's multidimensional geometric lattice structures: thus, a Johnston–style lattice structure would not be the most compact or efficient representation of Young's pitch relationships.

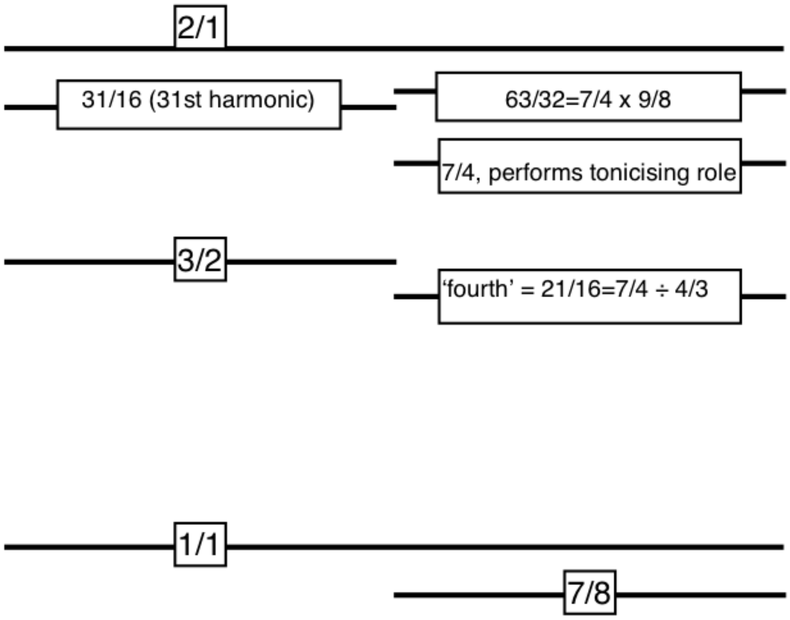


Figure 29: Dual–column one–dimensional map of pitch–space in The Pre–Tortoise Dream Music *(Young, 1964), highlighting main tuning relationships as described by Gann (1996, p.159)*

Note that 7–limit relationships are highlighted in the right-hand column. This representation is effectively a score-like (and in some cases, such as the 7/4-derived intervals, directly procedural) specification of interval relationships rather than a (direct) representation of their sensory or cognitive properties and relationships.

In addition, regarding the mapping of this piece's pitch–space, it should be noted that, given the presence of drone-based materials accompanying these intervals, a sensory/psychoacoustic model relating to degree of interaction of harmonic partials would also be illuminating. Although it might be expected that this would take the form of a dissonance curve (in a two-dimensional representation), for cases with sustained tones, dissonance judgements may relate more to periodicity-based effects than usual and may possess a greater tendency towards a plot of mathematical 'simplicity' of interval ratios; cf. Wishart (1996, pp.71–73) and Loy (2006, pp.56-8). This question of an appropriate dimensional model for Young's work will be discussed further below in relation to his installations. For the present, it seems clear that the use of harmonic series intervals as novel microtonal identities conforms best to a dimensional model which does not deploy extra (functional) dimensions per new prime factor.

Throughout the 1960s and following, Young's work with the Theatre of Eternal Music continued to investigate defined sets of harmonic series intervals through long–duration and rule–based improvisations, primarily grouped under the title *The Tortoise, His Dreams and Journeys* from 1964 onwards (Schaefer, 1996, p.31; Young, 2000, pp.1–6). Indeed, his subsequent general compositional development became focussed on the investigation of microtonal extended just intonation tunings in drone-based contexts through a variety of media: both live performances and electronic sound installations. The implications of perceptual issues and a conception of pitch–space appropriate to his later work in the field of drone–based installations (which provide his most extensive exploration of microtonal tunings) will be discussed below.

4.4 Young's Harmonic Drones as Environments/Ecological Structures and Embodied Exploration

4.4.1 Conceptual Background: Composition–as–Environment

Young began to experiment with the installation-based presentation of intervals through his *Drift Studies*[117] series, a long–term project which provided Young with a direction towards the most extensive and distinctive experimentation with microtonal tuning of his later work. This approach is grounded in an idea of Young's from 1962 of a *Dream House* which would contain sound installations playing sustained just-intonation-based intervals over extended durations to 'study the effect (if any) of long-term exposure to pure intervals on the human psyche and nervous system' (Gann 1996, p.172); see also Young (1969). The first public presentation of the *Dream House* environment took place in 1969 in Munich, curated by Heiner Friedrich, with a number of other short–term exhibits taking place before a long-term presentation began at the larger–scale Harrison Street venue[118] in New York (which served as combined living quarters and working environment for Young and Zazeela) from 1979–1985, supported by the Friedrich's DIA Foundation (Grimshaw, 2012, pp.118–9). Following a downturn in the oil market (upon which the DIA Foundation's investments were based), many of its larger-scale projects could no longer be supported, including the Harrison Street *Dream House*, resulting in Young's re–establishment of the project within his old Church Street loft, which remains its permanent home to this day (although a number of temporary

[117] The title referring to the tendency of analogue sine wave oscillators to drift (Gann 1996, p.172).
[118] Historically, a commodities exchange known as the New York Mercantile Exchange Building, it was suitable for the presentation of a number of concurrent sound installation environments (Grimshaw, 2012, p.119).

exhibitions have taken place in Paris, Lyon, Berlin and New York (*ibid.*, pp.119–120).

Such an approach to music, which might be thought of as ‘composition-as-environment’, relates to an oft–repeated association which he made between his music (both performed and installation–based) and environmental conditions and processes, such as the sound of storms from the vantage point of his parents’ log cabin in rural Idaho and the hum emanating from power lines nearby (Gann, 1997, pp.187–8; Schwarz, 1996, p.17).[119] Indeed, the explicit invocation of environmental concepts can be seen in Young's preferred term for his sound installations: *sound environments* (Young, 1969).[120] The first electronic sound–based installation piece/sound environment was inaugurated in his Church Street loft in 1966. The installations in this series comprise static ‘chords’/aggregates containing intervals based on prime number ratios, with the use of sine tones allowing for precise specification of the frequency content of the ‘sculpture’ without any harmonics of intervals undermining the perceptual clarity of the installation’s primary intervallic material (Young, 1969). (As a by–product of this creative choice, the interaction of complex timbres with a number of

---

[119] Indeed, Young's conceptualist *Compositions 1960* series also frequently highlighted a Caegeian engagement with the environmental context of a performance, though one with a more singular focus than that found in Cage's work. As Gann (1996, p.153) has put it '[i]f La Monte Young had not existed, it would be necessary to invent him, if only as a counterfoil to John Cage [...] If Cage stood for Zen, multiplicity, and becoming, Young stands for yoga, singularity and being.' Joseph (2008, pp.115–6) provides evidence that these differing positions were not simply a narrative or interpretive construct, citing testimony from Cage (1967, p.16, cited in Joseph, 2008) regarding a negative reaction to Young's work with the Theatre of Eternal Music, interpreting it as viewing the singularity of Young's environments as a regressive step in comparison with his own multiplicity. Indeed, Young's own testimony provides a strikingly similar interpretation as that found in Gann's poetic summary: 'I come from the point of view of the yogic approach to meditation, which is concentration and focus, as opposed to John Cage's approach to meditation which is a certain type of Zen where you let everything happen.' (Young, 1989b/1990).

[120] Indeed, Young's (1969) exegesis on his sound environments was delivered in an issue of an art periodical which also featured other work with a broadly ecological/environmental focus, including an essay on land art by Oppenheim (1969). In addition, Young's interest in psychoacoustics/perceptual issues finds a counterpart in an essay on Mach bands and psychophysical responses in relation to colour and shading (Bauer, 1969).

distinct partials as described by dissonance curves is no longer a factor which is relevant to the description of interval specification.) The principle of perceptual clarity and direct specification of intervallic materials would prove more important as Young's installations began to involve an increasing number of voices; since 1986, his installations have comprised upwards of twenty tones (Gann, 1996, p.175). This development, along with the concurrent exploration of smaller microtonal intervals, was facilitated by Young's acquisition in 1984 of a custom–designed digital synthesiser built by David Rayna which did not suffer from the drifting oscillators of earlier analogue synthesisers (pp.173–4). The later sound installations are therefore no longer *Drift Studies,* though they are a continuation of the *sound environment* theme; Gann nonetheless groups them along with *Drift Studies* under the more general rubric of *sine-tone installations* (p.173) while Grimshaw (2012) consistently favours *Dream House* as shorthand for both presentation space and the installation series.

4.4.2 Spatialising Young's Pitch–space

One key feature of these installations is that they allow a listener to explore various perspectives on the pitch materials by careful movement through the installation as acoustical phenomena influence the listener's perspective regarding the frequency content and structure of the pieces. The listener is encouraged by the nature of the materials to undertake an embodied exploration of the installation environment's sonic structure. The experience of this type of physical exploration of the *pitch–frequency space*[121] is described by Gann (1994, p.84) in relation to the installation entitled *The*

[121] *Pitch-frequency space* is used here as some of the frequency content is actually beyond the range of more accurate pitch perception, with the ninth and tenth octaves of the installation producing materials above 8040 Hz: $((2^4*67)*7.5)$, where 7.5 is the *subsonic* fundamental frequency of all of the

Base 9:7:4 Symmetry in Prime Time When Centred Above and Below The Lowest Primes in The Range 288 to 224 with The Addition of 279 and 261 in Which Half of the Symmetric Division Mapped Above and Including 288 Consists of the Powers of 2 Multiplied by The Primes within The Ranges of 144 to 128, 72 to 64, and 36 to 32 Which Are Symmetrical to Those Primes in Lowest Terms in The Half of the Symmetrical to Those Primes in Lowest Terms in The Half of the Symmetric Division Mapped Below and Including 224 within The Ranges 126 to 112, 63 to 56, and 31.5 to 28 with the addition of 119 (Young, 1994) :

> Walk into *The Base 9:7:4 Symmetry* and you'll hear a whirlwind of pitches swirl around you. Stand still, and the tones suddenly freeze in place. Within the room, every pitch finds its own little niche where it resonates, and with all those close-but-no-cigar intervals competing in one space (not to mention their elegantly calculated sum– and difference–tones), you can alter the harmony you perceive simply by pulling on your earlobe [...] *The Base 9:7:4 Symmetry* is [...] more textural [than a previous Young installation (Young, 1989), referring to the density of intervals]. Moving your head makes those tones leap from high to low and back, while that cluster in the seventh octave, with its wild prime ratios like 269:271, fizzes in and out. (Gann, 1994, p.84)

Thus, significant perceptual effects are engendered through the listener's larger bodily movements; those which change the body's orientation with reference to the sound source and acoustic environment of the installation space. One primary acoustical effect is that based on the amplification or attenuation effect of room modes/standing waves; some of the piece's intervals are more salient (due to being higher in amplitude) at

---

installation's harmonic components.

certain room locations. However, this action relates more to the changes in levels in the (relatively sparse) lower frequency materials within the installations. A more significant acoustical effect is the *comb filtering* effect (in an acoustically untreated room) which is the result of delayed versions of the drone being combined with the original signal due to being reflected from boundary walls; such a response can produce pronounced peaks and troughs in frequency responses which vary with listener position in the room. Gann's later, more detailed, account (Gann, 1996, p.188) notes the position–based variations with respect to room modes but not with respect to the effect of delayed reflections causing comb filtering, which produces position-dependent changes in level at higher frequencies (which therefore have the potential to be of greater relevance with respect to more of Young's freqeuency materials).

Although the effects of comb filtering may not normally be very audible with relatively broad–band stimuli (due to the densely packed nature of peaks/troughs at realistic distance–based time delays for small rooms, such as 10 milliseconds for 3.4 meters of path–length difference between direct and delayed sound—see Toole (2008, p.144–5)—the discrete nature of the stimuli in Young's installations in some frequency ranges is more likely to engender noticeable changes with this response than music with a significantly greater number of harmonic components from a variety of instrumental sources. As Toole (*ibid.,* p.145) illustrates, comb filtering with distances of this order will produce modes which are densely packed above 2 kHz to the extent that their effects would not be individually discernible; even within the region of 1–2 kHz, the peaks of comb filtering amplitude changes are likely to be of the order of around ten. These location–dependent comb filtering effects are thus most likely to account for the position–dependent changes in this frequency region (which is frequently the subject of the greatest number of intervals in addition to being a central symmetrical focus within Young's installation work; this will be discussed further below).

Of additional relevance in the quote from Gann (1994), above, is the mention of the effect of changing head position, which appears to be another component in the introduction of differing perspective to the installation experience. One aspect of this case is the relative changes in levels of higher–frequency materials due to head-shadowing effects as higher frequencies with wavelengths smaller than dimensions of the head and upper body tend to be diffracted around the impeding objects, creating frequency-dependent sound shadows over a relatively wide frequency range. (A perceptual application of this effect is its exploitation as a localisation cue known as Inter–Aural Intensity Difference (IID) or the Inter–Aural Level Difference (ILD): see Moore (2004, pp.235-238) for a survey of this cue.) A more particular aspect of this type of frequency–dependent filtering effect is to be found in the *head–related transfer function* (HRTF) response of the outer ears, head and upper body, which selectively attenuates or boosts higher frequencies based on the changing direction of incidence.

The normal aural and cognitive application of the HRTF is that the changing filter characteristics (which are a result of a changing direction of incidence of a sound source) can be used to assess localisation of a source; Moore (2004, pp.249–253) and Blauert (1997, pp.93–137, 304–312) provide summaries of research findings regarding this functional application of the HRTF in localisation.

The particular application/appropriation of the response in Young's installation work, however, lies not in the realm of localisation but in the facilitation of the perception of individual voices within the installations. Careful movements of body and head within the presentation space allow for certain intervals or clusters of intervals to be focussed upon. The dynamic changes (amplification/attenuation) applied to the source frequency spectrum which are the result of changing orientation of ears and head/upper body results in the individual voices becoming more individually salient. The HRTF response produces significant effects in this regard between 500 Hz and 16 kHz (Blauert, 1969/1970, cited in Moore, 2004, p.251). However, the application of the HRTF *for localisation* (in relation to resolving front-back ambiguity and details regarding elevation) may be confined to higher-frequency components of stimuli; Moore (pp.250–1) summarises current research to the effect that frequencies above 6 kHz are generally the most important for localisation effects (higher frequencies being based on the filtering action of the pinnae). For example, Langendijk and Bronkhorst (2002) completed one recent investigation which researched spectral cues above 4 kHz, concluding that components above approximately 6 kHz provided the most significant contributions to localisation judgements. However, Gardner and Gardner are cited by Moore regarding the potential contribution of components as low as 3 kHz (Gardner and Gardner, 1973, cited in Moore, 2004, p.250).

Since the general lower limits noted above for the appropriation of this spectral response for localisation effects of components is above the frequency range for accurate pitch judgements, the higher frequency *localisation application* of the HRTF response is not, according to this view, relevant to an explanation of the direction-dependent perceptual segregation of frequencies in Young's installations. Nonetheless, the significant changes in amplitude within various regions in the pitch-sensitive range of the lower frequency spectrum (above 500 Hz) are likely to be relevant in terms of *encouraging individuation* (and may be considered one of the main contributing factors to changing perspective/individuation within the installation). My own personal experience of Young's most frequently–deployed recent sound installation environment (Young, 1991) at the Church Street *Dream House* suggests that perceptual changes with respect to head/ear orientation are as important as location–based changes within the room. This is corroborated in accounts by Krueger (2008, pp.13–4), Riley (1996, p.21) and, as quoted above, Gann (1994, p.84). Krueger's account is notable for its mention of the subversion of traditional discrete localisation[122] through drone–based immersion and position–and–orientation-dependent filtering.

> Upon entering the front room, I realise that the frequency and intensity of the tones vary in each ear and that the changes correlate with even the slightest movement. The sound source seems to be, obviously, the huge speakers in each corner, yet this sound cannot be localised in the conventional sense. It does not emanate from somewhere, it simply is. The frequencies are located in space at an extremely fine resolution occupying it in a stable and reliable way. If I place an ear at a position in three-dimensional space, I will hear a particular tone, and if I return to that location the tone will be heard again. I can cycle through a sequence of frequency combinations by initiating a sequence of movements. By doing so, I can choreograph an acoustic composition. (Krueger, 2008, pp.13–14).

In relation to a personal exploration of the HRTF–based effects, the use of changing orientation of head and ears on the higher frequencies is a particularly striking feature of

[122] This type of subversion of discrete localisation has been termed diffuse localisation by Negrão (2010, p.7), on the basis that it prioritises extension and immersion rather than discrete structures.

the experience. Continuous repetitive movement such as making a circling motion with one's head produces a pronounced degree of cyclical individuation/arpeggiation[123] of a number of the higher voices. In addition, a repetition of Gann's experiment of tugging on an earlobe does bring about perceptible changes of a high frequency (but pitched) component (perhaps in the region of 4 kHz). In summary, there appear to be a number of acoustical factors which influence the perception of the frequency structures of Young's installations in various ways. These factors are summarised in figure 30, below.

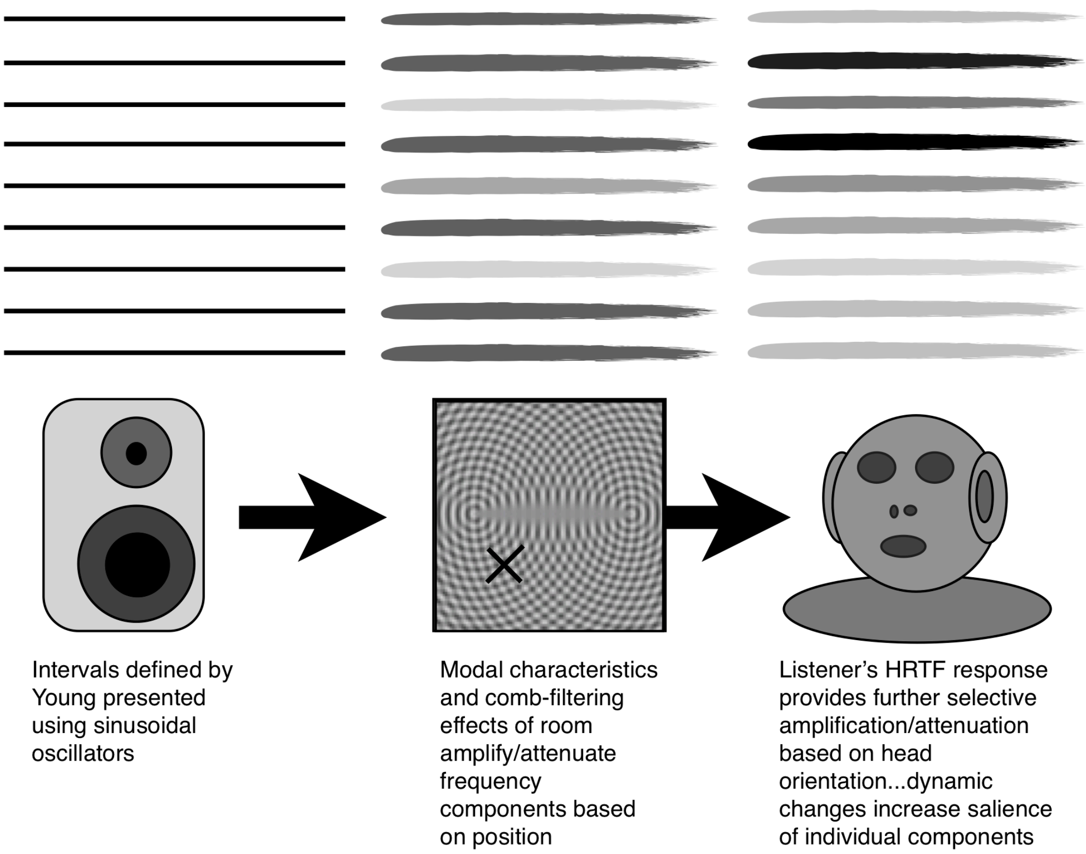


Figure 30: The relationship between source material, room, listener HRTF and the resulting percept in Young's sound installations

[123] This occurs because of the application of what Bregman (1990) terms the 'old-plus-new heuristic'.

4.4.3 Defining Young's Pitch–space: Interactions Between Pitch Specification and Perceptual Differentiation

Young's pitch–space is thus articulated through a spatialisation/differentiation process which includes components relating to room acoustic effects alongside the impact of an exploitation of the HRTF response of an individual listener. These effects are especially significant in allowing for the perceptual differentiation of individual frequency components in dense intervallic contexts. In the case of Young (1994), such pitch/frequency material is particularly dense in higher octaves. As can be seen in figure 31 (following page), the area around the octave boundary of the sixth and seventh octaves (above the drone) contains the vast majority of the intervals in the installation (20 out of 35). The diagram organises intervals by octave, with all intervals above the vertically-central 1/1 interval appearing in the octave number indicated and those below this line appearing one octave below this figure.

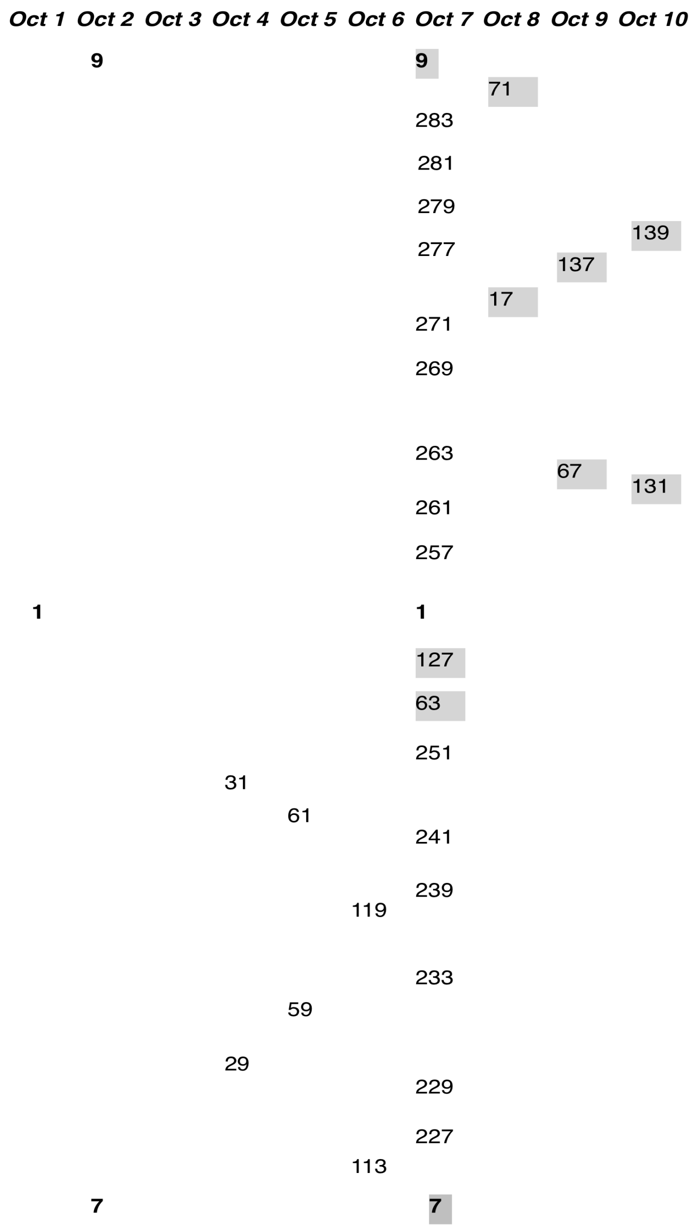


Figure 31: Octave grouping of ratio-based intervals in The Base 9:7:4 Symmetry in Prime Time… *(Young, 1994), after Gann (1996, p.185)*

Numbers indicate tunings based on multiples of fundamental frequency (this is set at 7.5 Hz, although the lowest sounded component is a 30 Hz drone two octaves above this—see Gann p.184). Vertical ordering is provided by interval size (Gann's original also provides cents). Intervals highlighted in gray are transpositions of harmonics indicated. Grimshaw (2012, p.135) provides another version of this material, based on pitch-chroma spirals.

The representation above shows the significant degree of microtonal density which is present in this piece: the intervallic materials reside exclusively within a span of a minor third (although offset within various octaves). In addition, as noted above, the interface between the upper part of the sixth and lower part of the seventh octaves contains a dense microtonal cluster of twenty of these intervals; thus, they are literally encompassed within a single, untransposed minor third.

The reason behind the choice of this particular octave boundary as the frequency region for such a dense presentation of intervals is illuminated if we consider in detail the characteristics of the frequency/amplitude response of the HRTFs. As Kendall and Martens (1984, p.3) note, researchers have found significant differences in individual HRTF responses from different human subjects, although a number of common trends in characteristics can be discerned, thus simplified versions based on common trends may be sufficient for the facilitation of localisation based on spectral cues. Based on this supposition, a simplified human head (including pinnae) and torso model has been used in many programmes of sound localisation research. A constructed version of such a model, the KEMAR (Knowles Electronic Manikin for Acoustic Research), is based on an average of measurements obtained from male and female subjects; its characteristics are discussed in Burhard and Sachs (1975). Allowing the assumption that the average of the measurements which contribute to its design is reasonable, the HRTF data obtained from the KEMAR (Gardner and Martin, 1994) can be considered on the basis of providing an insight into generalised human HRFT characteristics.

In the case of Young (1991), the bulk of the pitch materials (twenty voices) is to be found in a range from 1680 Hz (five octaves above the seventh harmonic) to 2160 Hz (five octaves above ninth harmonic), a frequency region which sees significant variations in amplitude with changing direction of incidence; see Mokhtari et al. (2009, pp.2–3). Given the combination of comb filtering and modal responses for this region, it is likely to produce a significant degree of variation with respect to listener movement. Young's presentation of materials is therefore arguably tailored to produce maximum variation in salience/'perceptibility' for the frequency range which the greatest number of its voices inhabits. None of Young's published statements suggest that he has followed research into HRTF data or has explicitly taken comb filtering into account; it is most likely that he has decided on this configuration based on the experience of effects created by previous installations. The concentration of intervals within this frequency range can also be found in other installations (Young 1989; 1990), discussed in Gann (1996, p.1974–185), providing some corroboration that this choice is not merely a case of singular serendipity. Thus, Young'' compositional application effectively subverts two key embodied aspects of hearing to allow for a location–and–orientation–dependent 'playing' of the pitch-space by the audience, facilitating an embodied exploration of pitch-space as an almost tangible sonic environment. In this, the full multi-modal experience of embodied exploration is arguably a key determiner of the resulting cognitive structuring on the part of the listener–explorer.

4.4.4 Henry Flynt's 'Acognitive Culture' as Theoretical Rationale for Young's Embodied Pitch–spaces

As part of the general ferment of ideas which were generated and cross–pollinated in the early New York Downtown scene, one of Young's associates, conceptualist Henry

Flynt, developed a number of ideas relating to the connection between the materials and structure of artistic activity and perceptual/cognitive issues. Flynt's ideas will now be presented here for the purposes of developing a broader theoretical perspective on the embodied listening/exploration process of engagement with Young's sound environments.

Regarding the relationship between composed structure and perceptual experience in Young's installation work, Flynt has noted that 'you [...] have to create the piece from the mechanical cues they were providing' (Flynt, 2006, 4'25-5'15). Although this assessment is primarily descriptive (provided as part of a retrospective survey/narrative relating to the legacy of the early Downtown New York scene) it is nevertheless a summary which succinctly describes the unusual relationship between the structured materials provided by Young and the resultant piece as experienced by an auditor. In doing so, such pieces arguably partially avoids the pitfalls which Flynt's earlier theorising had discerned in what he terms *structure art*, defined as any art–form in which formal structure is of overriding primary importance. In his early theorising, Flynt provides a clear musical exemplar in the case of integral serialism, where the structural relationship defined by the composer *does not* provide structures which are directly accessible in perception; in such cases, the work's 'cognitive pretensions are utterly wrong' (Flynt, 1963).

Flynt's preferred solution here is to provide for an expanded form which is not concerned with 'being music' (i.e. normal musical syntax and structural concerns) and which becomes more related to the structural concerns themselves, rather than its materials, becoming *concept art* through an equation between structure and concept (Flynt, 1963). Indeed, as Labelle (2006, p.68) has noted, Flynt's version of conceptualism owes more to perceptual aspects than other strands of conceptualism. His 2006 assessment of Young's installation work of the 1980s and later is therefore of relevance here as an analysis which valorises perception/reception and the embodied experience of physically exploring the work, thus indicating that, at the very least, it belongs to a form of structure art whose 'cognitive pretensions' are not 'utterly wrong' and therefore belong to a more favoured category within artistic practice where the creator's structure and the perceiver's structure are clearly connected, producing what he terms 'an (associated) artistic structure experience' (Flynt, 1963). In addition, the conceptual implications of this radically new form of engagement with pitch structures—through embodied exploration—could also be seen as the mark of a conceptual inflection to this part of Young's oeuvre.

More fundamentally (and more radically), the foregrounding of embodied perceptual experience in Young's sound environments could be examined from the perspective of a possible compatibility with Flynt's concept of *acognitive culture* (Flynt, 1962), which he defines in general terms as 'a concept of "recreation" (resulting from analysis of the concept of recreation) for conscious organisms.' This cultural form is intended to replace a wide range of cognitively-based activities which Flynt repudiates, including 'pure mathematics (and structure art and games of intellectual skill), and Serious Culture/all art/literary culture/science fiction/music.' Flynt's acognitive culture is thus defined most specifically in negative rather than positive cases. Of particular relevance here are Flynt's views on music composition, which is treated as a particularly problematic case due to his analysis that the primary existence of compositions lies in the domain of the written specification of activities and not in the activity of the participants and the primary generative activity relating to the development of the written specification. However, given Flynt's focus on the perceiver's act of creation involving an 'immediate' (i.e. non-mediated through an elaborate memory-based mapping of its structure) sensory-based experience of the piece through the implied exploration of what he describes as the 'mechanical cues', his perspective on Young's installations would appear to suggest that they possess a degree of compatibility with the idea of acognitive culture. This Flynt–derived acognitive perspective on Young's work, whilst clearly not plausibly totalising (for Young's work still remains structure art at one level of analysis) nonetheless raises important questions regarding the role of map-like cognitive structures in such cases.

The reception–centered focus on the embodied exploration which Young's sound environments afford bears a striking resemblance to another 'acognitive' theoretical perspective, that of embodied cognition (see preliminary discussion of this theory in section 1.3.4 of the introductory chapter). This movement within psychology, cognitive science and philosophy seeks (to varying degrees) to embed, situate or connect the cognition of an agent in an environment to the environment's interaction possibilities or those of the tools which are available to it (Lakoff and Johnson, 1980; Varela et al.,1991; Clark, 2008; Rowlands, 2010; Shapiro, 2011). In a manner consistent with the aforementioned assumptions of embodied cognition (discussed further in chapter six), the intersection between human-embodied exploration and the composed environmental structures within Young's installation pieces provide maps which inform their cognitive organisation for the active listener–explorer. The most relevant cognitive map of pitch structures is therefore, according to this analysis, the three–dimensional *spatial–*

experiential map of pitch–space. The type of geometric mapping of pitch–space found in Johnston's theories is somewhat superfluous in the context of an environmental setting which spatialises pitch. It is therefore my contention that this facilitation of an embodied exploration of microtonal pitch–space is one of Young's most original contributions to the field of microtonal music and it is interesting to note its congruence with the ideas of his contemporary, Henry Flynt.

4.5 Young's Interval Choices: Structural Choices and Perceptual Issues

4.5.1 Formal Structures as Approached Through Perceptual Circumstances

As noted above, the structures which Young provides in his early work are sometimes chosen to simplify listener perception of the intervals, as in the seventh harmonic 'drone' facilitating perception of seven–based intervals in the *Pre–Tortoise Dream Music* (Young, 1964) and the general use of sinusoidal waves for each voice to avoid extra harmonics obscuring the clarity of the intended structure. In Young's later installation piece (Young, 1991), this emphasis on facilitating the perception of intervallic materials leads him to present his greatest density of intervals within the sixth and seventh octaves above a 7.5Hz fundamental[124] in a frequency range where a listener's HRTF response will engender maximal amplitude variation leading to the differentiation of individual intervals with head movements. The simple result of this process is that embodied exploration (head/body movements) provides the opportunity

[124] With a drone at 30Hz, two octaves above this, as the lowest sounded frequency. However, a periodicity-based subsonic percept is present, as noted in Grimshaw (2012, p.141).

to explore the installation's pitch–frequency structure based on the amplification/attenuation of its component voices. One aspect of this is that such pieces are experienced as a movement-calibrated mapping of frequency space to physical space and, as proposed above, such an experience may be primarily the subject of an embodied cognitive model.

However, one corollary of this perspective is that it assumes the gradual exploration or revealing of a piece's pitch–frequency structure. Assuming, for the present purposes, that the momentary experiential sensuousness of the rich multi-modal sound-space environments created by Young may dominate over a cognitive model based solely on pitch-frequency relationships, the question arises as to what perceptual and cognitive role Young's formal pitch–frequency structures play in the installations' reception. Gann (1994), as noted above, describes the perceptual results of embodied exploration of Young (1991), highlighting the perceptual effect of small movements on its central twenty–interval cluster, though not explaining the acoustical/perceptual bases for this. However, the clue is present in Gann's encouragement to listeners to experience the altered harmony encountered when the pinna's orientation or shape in relation to the sound is altered, with the explicit mention of an 'altered harmony' when a listener tugs on their earlobe implying a change of perspective of the dense yet spatially–diffused presentation of microtonal intervals:

> Within the room, every pitch finds its own little niche where it resonates, and with all those close–but–no–cigar intervals competing in one space [...] you can alter the harmony you perceive simply by pulling on your earlobe. (Gann, 1994, p.84)

Thus, Gann's conceptualisation of the piece appears to be very much based on a *source–filter* idea whereby the compositional structure is mediated by the perspective introduced by listener location and bodily presence/orientation to produce a harmony from the supra-set/superstructure of harmonic components within the composition.

A further clue as to what Gann considers to be the salient aspects of the composed superstructure is to be found elsewhere in the same article. At the outset, he summarises the piece as a set of intervallic variations on sevenths and ninths over a low drone:

> [Young's] math gives him a variety of sizes of seventh and ninth intervals, *all closing in on the octaves over a fundamental B* (actually a quartertone flat). In each octave, all the pitches are within the major third between A and C sharp. Imagine a ladder of 10 octaves of the same pitch. Now imagine the rungs bent and diffracted into lots of different tones, the lower rungs slightly lowered, the upper rungs raised. And because even these exotic overtones of a single low pitch are theoretically more harmonious than the scientifically irrational tuning of a modem piano, you're hearing a wild frontier of tonality that has never been explored, the outer edge of consonance.
>
> (*ibid.*) [italics mine]

In this case, Gann is referencing the somewhat reductionistic view of microtonal intervals as minute chromatic alterations of 'standard' intervals. However, this contradicts Young's own stated position, which is that of the committed microtonal essentialist rather than relativist. Young has noted that 21/16 is a unique identity which is not perceived as a poor rendering of a 4/3, though musicians and listeners might need practice and/or training to hear the difference for intervals which are similar in size (Young, 1989b/1990, p.5).[125] Nonetheless, Gann's invocation of this idea is here used as a convenient shorthand for conceptualising the relative size of these microtonal intervals. The later part of the description arguably sets out to illuminate the distinctions between these different intervallic variants: each interval is a 'rung' in a harmonic series ladder which is derived from relatively small deviations from the drone and its octaves.

Thus, Gann's reading emphasises the variations in the piece's harmony which a listener's embodied exploration can engender, whilst nonetheless maintaining a focus on the underlying compositional structure (through the sevenths/ninths summary and the ladder metaphor). This perspective on the piece is consistent with the term 'sculpture', which is often used in descriptions of Young's installations—e.g. Gann (1997, p.193) and Grimshaw (2012, p.116) as a shorthand for the static nature of the originating sound materials. The implication is that the pieces offer listeners different spatial perspectives on a composed 'object' made of periodic vibrations.[126] In this analysis, these pieces' frequency scores are one 'half' of the salient compositional structures, with the listener's own spatially–mediated interface with the intervals providing the other 'half'; to examine these pieces simply as networks of frequency ratios without reference to the above-mentioned issues in auditory perception is to consider them as two–dimensional renderings which are missing crucial details of lighting whereby depth can be reconstructed. Although Gann (1994) emphasises the

---

[125] This is consistent with Young's periodicity-based concept of interval identities, as set out in Young (1969).

[126] Indeed, Grimshaw (2012, p.116) asserts that Young's *Dream House* approach embodies 'one of the most complete interpenetrations of music and sculpture, or, more specifically, spatial and temporal art in the history of Western culture.' Krueger (2008, p.14) describes Young's approach as 'a way to qualify space, to insert an architecture of sound into an otherwise unoccupied volume.'

textural density of (Young, 1991), in contrast to (Young, 1989), this potential for perceptual density is clearly obviated by the choice of the seventh octave region for the twenty–interval cluster, with its significant HRTF variations. The salient perceptual result, then, is of a movement–generated arpeggiation of the intervals within this cluster based on the HRTF filtering effects.

4.5.2 Focus on Formal Structuring Attributes

Turning to the originating pitch–frequency structures themselves, Young's concerns appear to have remained remarkably consistent over a number of years of exploration. As a number of authorities have pointed out (Gann, 1996, p.160; Grimshaw, 2012, p.131), Young avoided major and minor thirds and sixths in his early *Trio for Strings* (from 1958) and these (5–limit) intervals, a central feature of Western common practice tonality, are also conspicuously absent from his tuning installations.[127] In their place, Young, according to his own testimony (Young, 1989b/1990, p.2), regards the interval of 9/8 as one of central importance with respect to how it can be divided into novel microtonal intervals and how it can feature in chords built on the seventh harmonic as root. As Gann (1996, p.168) notes, Young's *Well–Tuned Piano* (Young, 1964/1973/1981–present) drove his interest in the intervallic region of the harmonic series between the seventh and ninth harmonics and provides some of the structural basis for Young's later installations; Gann further notes that this interval region is divided by Young into two 9/8 intervals, with a *comma* of 64/63 between the two intervals. As an illustration, this region can be organised into a chord based on the ratio

[127] Young himself has speculated that part of the motivation for eschewing these intervals is that they are subject to particularly poor renderings in 12TET (Young, cited in Gann, 1996, p.161).

56:63:64:72 (p.173). The 56:63 simplifies to 8:9 (or 9/8), as does the 64:72.[128] The symmetry of this configuration is one which Young regards as particularly attractive and the symmetrical structural articulation has found a central place within his later tuning installations; see discussions in Young (1989b/1990, p.3) and Gann (1996, pp.178–187). The issue of symmetrical pitch–frequency structures within the installations will be discussed further below.

For the present purposes, the issue of the interval identities themselves is an even more fundamental issue in the assessment of microtonal structures in Young's installation work. As noted above, Young’s interest in intervals is concentrated within a space of approximately a major second on either side of the octave (between the seventh and ninth harmonics). Gann (1996, p.175) traces this constant feature of Young’s work as far back as his early *Trio for Strings.* Young's particular focus within the gamut of harmonic series intervals came to be the harmonics within the series which are described by prime numbers (in addition to the ninth harmonic, which is a compound of two 3–based fifths, which is presumably exempted on the basis of its salience as a harmonic occurring early in the harmonic series). This is because prime number harmonics constitute unique interval sizes within the series, in contrast to non-prime harmonics which are merely transpositions of those which occur earlier in the series. Grimshaw (2012, p.137) states that it is for this distinctiveness and ‘their aurally discernible qualities’ that Young favours prime harmonics; they constitute unique identities for Young in a somewhat analagous manner to that with which Partch and Johnston had regarded them, although his concept of uniqueness is based on sonority

[128] The origins of this type of approach can be found further back in Young (1963) *The Pre-Tortoise Dream Music*, which features 56:63:42 or 8:9:6 on the seventh harmonic (Young 1989b/1990. p.2).

and periodicity, not on function. Young's usage is distinctive in that he uses these materials in a manner consistent with the originating harmonic series as a one–dimensional scale rather than a multidimensional space; the addition of higher primes is not treated as necessitating the addition of an extra dimension in a pitch-space of functional connections, as it is in the theories of Partch and Johnston. Since Young deploys particularly high primes (and insists on their unique individual identities), this is perhaps fortunate with regard to the possibilities of a relatively compact model for his pitch relationships! The structural possibilities of Young's installation–based explorations of harmonic space encourages the proliferation of higher prime intervals; as Grimshaw (*ibid.,* p.137) notes, the *Dream House* installations are not constrained by the standard archetype of scale forms which are replicated at each octave.

Young's greatest interest is in intervals which occur near octaves (above or below), resulting in the frequent deployment of intervals which occur near the seventh and ninth harmonics. As discussed above, Young avoids the use of 5–based intervals (such as standard just–tuned thirds or sixths), removing the option of using these intervals as structural linchpins. In addition, the perfect fourth (4/3) is unavailable for scale construction due to its not directly occurring within the harmonic series (though it does occur indirectly as a relationship between harmonics rather than directly with the fundamental). Although close variants of this interval exist in the harmonic series, they are the result of 'more complex' periodicity patterns such as 21/16 or 43/32. The perfect fifth (3/2) relationship is the only one of the simpler relationships left from those which form the basis of the just diatonic scale. However, since it occurs, in Young's conception in comparative isolation, given his preference for eschewing fourths and 5–limit sixths, it does not offer the possibilities of defining an interval region within which to explore microtonal divisions that the pairing of the seventh and ninth harmonics does. Thus, the choice of these harmonics as the subjects of an important structural articulation in Young's work is unsurprising when examined in this context.

4.5.3 Procedural Generation of Materials and Symmetry in Formal Structures

As Young investigated the prime-based intervals close to the octave, his attention was drawn to formulae which described relevant primes by a friend, mathematician and Downtown artist–composer Catherine Christer Hennix (Gann, 1996, p.175; Hennix, 2010). Gann relates that the first such formula investigated in this regard is that which describes *Mersenne primes*. These are primes which are *Mersenne numbers*, obtained by evaluating the function 2^p-1 (where p is itself a prime number); Gann notes that prominent examples from early in the harmonic series include 31, 7 and 3. With Hennix's help, Young's investigations of prime number harmonics charts an expanded field which included intervals which were 'near misses' from octaves of primes, obtained by the formula $\boldsymbol{p * 2^n-1}$, christened *Young Primes* or P_{YI} by Hennix (Gann, 1996, pp.175–6). Gann outlines a further extension of this principle yielded a set of primes which are close to octaves of non–primes, classed as a second type of Young Prime, P_{YII} ,with candidates for such numbers generated by the formula $\boldsymbol{p * m^n}-1$, where p is a prime and m is a positive integer (excluding powers of 2) and n is an integer greater than 1; Gann provides the example **of** $\mathbf{2*3^2-1=17}$ (17th harmonic as just below an octave of the 9th harmonic). It should be noted that the formula above merely yields *possible candidates* for the class of Young Primes (P_{YII}) and frequently generates non-primes.

Another set of (harmonic) numbers generated by the formula which are sometimes used by Young is the set of *Young Integers* (Gann, 1996, p.176), which are non-primes produced by the formula, including the 9th harmonic/major second and the 63rd harmonic. This procedural rationale for the focus on intervals adjacent to prominent harmonics which occur relatively early in the series (Gann, 1996, p.176) is the detailed exposition of the principle which Gann (1994) described in more intuitive terms as a 'harmonic ladder' (Gann, 1994, p.84). Gann (1996, p.176) also highlights the further level of structural articulation in Young's later sound installations which is provided by the phenomenon of *Twin Primes*, pairs of prime–numbered harmonics separated by two (e.g. 21&31, 59&61, 137&139) and adds that, structurally, such harmonics also reinforce octaves of the fundamental through their difference tones (though the resulting periodicity for Young's later installations would generally be subsonic in nature).

The procedural basis of Young's prime–and–octave approach is clearly visible in the tuning scheme of *The Romantic Symmetry (over a 60 cycle base) in Prime Time from 144 to 112 with 119* (Young, 1989). Gann (1996, p.179) provides a frequency chart for its twenty two intervals, relative to a subsonic fundamental of 7.5 Hz (with 60 Hz as the lowest sounded component). Like *The Base 9:7:4 Symmetry* (Young, 1991), this piece deploys its intervals between the seventh and ninth harmonics, frequently deploying both Twin Primes and the two classes of Young Primes (and octaves of same), with the addition of the prime 113 and octaves of 7, 9 and 63, in addition to the frequent reinforcing of the drone (and fundamental) at various octaves.[129] The title (reproduced

[129] Gann (1996, p.178) notes that the frequent octave doublings of various intervals is the (humorous)

above) provides a significant part of the procedural basis for the piece's generation; primes *and* octaves of primes are selected within the region of harmonic numbers 112 to 144, with the addition of 119 and some other alterations (transpositions) to provide a symmetrical structure (detailed below after Gann (1996, pp.179–80). All discussions of structural features below are derived from this source. The procedural genesis of this installation is best illuminated by viewing a tuning chart (figure 32, next page).

origin for Young's choice of the appellation ‘Romantic’.

Harmonic no.	*Cents from fundamental*	*Descriptions*
1152	[204]	($9*2^7$) octave of 9
1009	[1173]	($9*7*2^4$) octave of 63
556	[143]	($139*2^2$) octave of twin prime
524	[40]	($131*2^4$) octave of prime
274	[118]	(137*2) octave of twin prime
268	[79]	($67*2^2$) octave of prime
144	**[204]**	**($9*2^4$) octave of 9**
142	**[180]**	**(71*2) oct of Young prime (P_{yII})**
136	**[105]**	**($17*2^3$) octave of prime**
128	**[0]**	**(2^8) octave of fundamental**
127	**[1186]**	**Young prime (P_{y1})**
126	**[1173]**	**(9*7*2) octave of 63**
119	**[1074]**	**(17*7)**
113	**[984]**	**prime**
112	**[969]**	**($7*2^4$) oct of Young prime (P_{y1})**
61	[1117]	twin and Young prime (P_{y1})
59	[1059]	twin prime
31	[1145]	twin and Young prime (P_{y1})
29	[1030]	twin prime
16	[0]	(2^5) octave of fundamental
14	[969]	(7*2) octave of Young prime (P_{y1})
8	[0]	(2^3) oct of fundamental and drone

Figure 32: Harmonic numbers chart and procedural origin for The Romantic Symmetry (over a 60 cycle base) in Prime Time from 144 to 112 with 119 *(Young, 1989), after Gann (1996, p.179)*

The central region (144 to 112) is indicated in bold to clearly delineate between it and the symmetrical structures above and below this region.

Gann here draws attention to a number of symmetrical characteristics, some of which are the by–product of Young's procedural approach and some of which are somewhat arbitrary additions to maintain symmetry. This symmetry is about an axis at the 127th harmonic (not the octave/128th harmonic), with the requirement of the additional 119 non-prime harmonic so that there are equal numbers of intervals in this group above and below the 127th harmonic). There is a more fundamental symmetry to the use of the 119th harmonic, as it is a 7th harmonic of a 17th harmonic and therefore balances with the 136th harmonic above the mid-line ($136=17*2^3$); Young is also cited to the effect that he particularly liked the resulting sonority when 119 was added (Young, cited in Gann, 1996, p.180).

Away from this central cluster, octaves of prime harmonics in the range 144 to 112 are transposed to upper and lower octaves as follows: below 127, transpose to lowest possible octave (i.e. the originating prime factor, resulting in 61, 59, 31, 29 (all Twin Primes), with the exception of the 7th, which is sounded above the 2^3-based octave (hence, becomes the 14th harmonic) and with the addition of a 2^5 octave at the 16th harmonic. Above the boundary of the 127th octave, the harmonics 139, 137, 134 (octave of 67) and 131 are transposed upwards to make a corresponding octave-symmetrical structure with the two octaves below the central 144–112 region (resulting in harmonics at 268 (octave of 67), 274 (octave of 137), 524 (octave of 131) and 556 (octave of 139). The final two intervals are at 1008 (an octave of 63) and 1152 (an octave of 9), designed to be octave-symmetrical with the first two intervals after the drone and providing the closing boundary 9th harmonic (specifically, its compound octave) for the entire ‘7th to 9th’ region, along with an adjacent 7th harmonic of this interval (an octave of 63) in the octave below, mirroring the adjacent 7th and octave at the lower end of the installation, along with the 126th harmonic (an octave above 63). As can be seen, the procedural rigour in the generation of materials is mediated by a matching (if somewhat looser) concern for symmetry in the arrangement of intervals within different octaves (see figure 33, below).

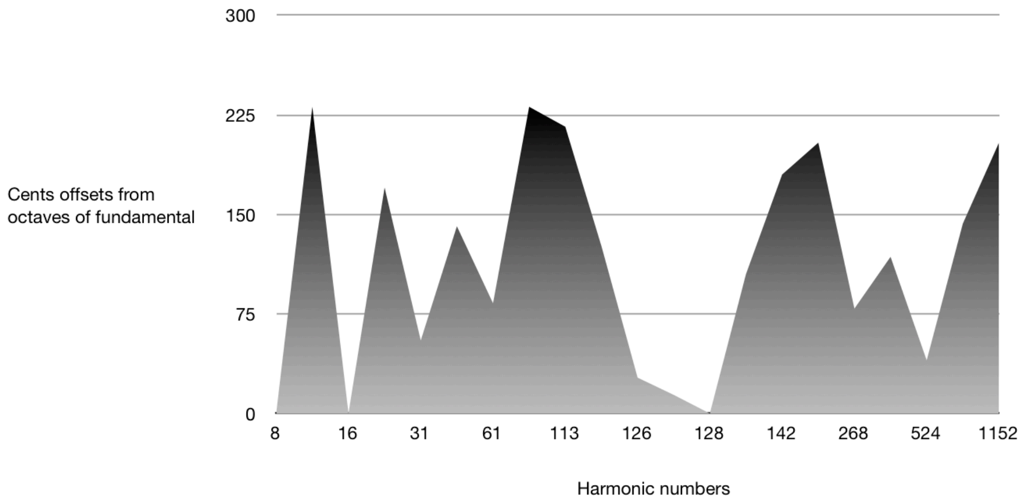


Figure 33: Intervals considered as deviation from octave in The Romantic Symmetry (over a 60 cycle base) in Prime Time from 144 to 112 with 119 *(Young, 1989) after cent figures provided in Gann (1996, p.179)*

These figures have been changed to cents offsets above/below octave rather than absolute cents values above given lower octave boundaries to illustrate the symmetrical effect.

The perceptual effect of this arrangement is somewhat similar in approach to (Young, 1994), most significantly in relation to the arrangement based on a central cluster containing a relatively dense intervallic presentation surrounded by sparser intervallic presentations exhibiting procedurally–derived symmetry. However, the density of intervals in this central section is much reduced in comparison with the later piece: nine voices in comparison with twenty—as Gann (1994, p.84) has noted, the effect is more ‘melodic’ than ‘textural’. However, this is still a case of materials which facilitate direction–dependent individuation. The frequency range of this central cluster is 840–1080 Hz (from harmonics 112 to 144), meaning that any variations in amplitude will be based on head/upper body aspects of the HRTF. Although the relative interval density is reduced when compared with Young (1991), this region still contains a significant number of intervals within a small frequency range and requires such individuation for the sake of perceptual clarity. As such, the experiential modality of a listener's engagement with the installation is broadly similar to the later work.

4.5.4 Dimensionality Revisited

Young's later installation work is illustrative of the extremely problematic nature of a Johnston-style ‘dimension–per–prime–limit’ model of pitch–space, in an even more extreme case than that discussed earlier in relation to *The Pre–Tortoise Dream Music* (Young, 1964). His early use of the 31st harmonic in (*ibid.*) alongside predominantly lower prime limit intervals provides an early indication that incremental functionally-based dimensional proliferation is not his main concern or conceptual perspective. In (Young, 1994), as in (Young, 1989), the frequency materials are produced using the procedural model noted above, leading to a preponderance of high prime factors (figure 34, below, p.231). The sheer number of these new primes (which are only rarely deployed as factors in new frequency ratios) in his later installations coupled with the harmonic drone–based singularity of the percepts involved here arguably undermines any tendency towards a functionally–based spatial model of their reception. Thus, Young’s installation work resists this type of multidimensional representation. The most viable spatial functional model may be as simple as a scalar one–dimensional structure, based on Young's interest in adjacent intervals (i.e. close together in the one–dimensional scale) and their relationship with the fundamental frequency sounded as a drone.

Harmonic no.	*Cents from fundamental*	*Descriptions*
2224	[143]	(139*2^4) octave of twin prime
2096	[40]	(131*2^4) octave of prime
1096	[118]	(137*2^3) octave of twin prime
1072	[79]	(67*2^4) octave of prime
568	[180]	(71*2^3) oct of Young prime (P_{yII})
288	**[204]**	**(9*2^5) octave of 9**
283	**[174]**	**twin and Young prime (P_{y1})**
281	**[161]**	**twin prime**
279	**[149]**	**(9*31)**
277	**[136]**	**prime**
271	**[99]**	**twin and Young prime (P_{y1})**
269	**[86]**	**twin prime**
263	**[47]**	**prime**
261	**[33]**	**(9*29)**
257	**[7]**	**prime**
256	**[0]**	**(2^8) octave of fundamental**
254	**[1186]**	**(127*2) octave of prime**
252	**[1173]**	**(9*7*2^2) octave of 63**
251	**[1166]**	**Young prime (P_{y11})**
241	**[1095]**	**Young prime (P_{y11})**
239	**[1081]**	**prime**
233	**[1037]**	**prime**
229	**[1007]**	**twin prime**
227	**[992]**	**twin prime**
224	**[969]**	**(7*2^5) octave of 7**
119	[1074]	(17*7)
113	[984]	prime
61	[1117]	twin and Young prime (P_{y1})
59	[1059]	twin prime
31	[1145]	twin and Young prime (P_{y11})
29	[1030]	twin prime
9	[204]	region boundary
7	[969]	region boundary
4	[0]	(2^2) octave of fundamental

Figure 34: Frequency ratio chart for The Base 9:7:4 Symmetry in Prime Time...*(Young, 1994) after Gann (1996, p.184)*

Frequency components in bold occur within the 'central' sixth-seventh octave boundary

However, it is also possible to conceptualise the formal structure of Young's installation pieces in a two–dimensional manner which might draw attention to the salient properties of some of these intervals. This type of representation has been used in figure 33 above, for (Young, 1989) and is of interest as a potential general model for Young's installations. In structural terms, a representation which indicates interval size in terms of deviation from the octave provides a clear visualisation of the symmetrical structure between the central and outer regions of the installation, complete with peaks (marking distance from octaves of fundamental) which generally correspond in terms of relative position and magnitude. This representation is presented in figure 35, below, for intervals in (Young, 1994). Indeed, when compared with figure 33 for (Young, 1989), it is clear that the symmetry is even more pronounced in the present piece.

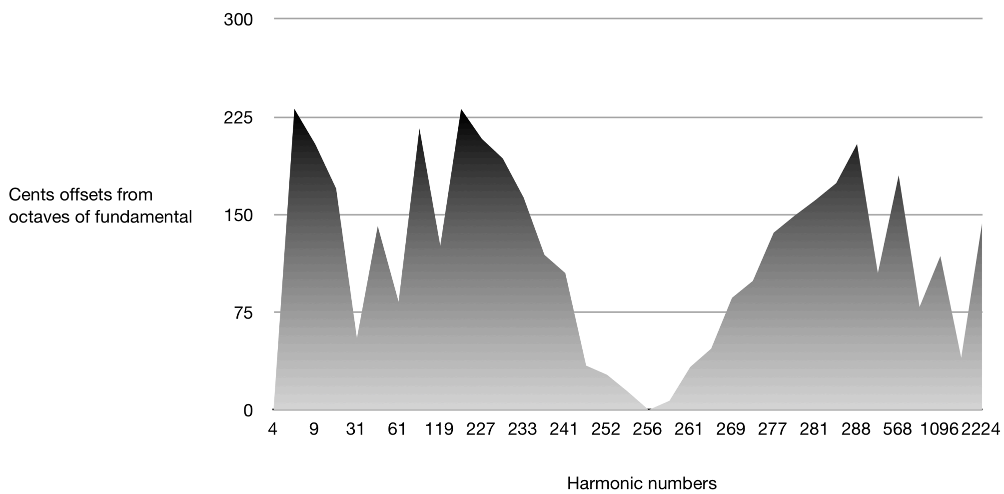


Figure 35: Intervals considered as deviation from octave in The Base 9:7:4 Symmetry in Prime Time*...(Young, 1994) after cent figures provided in Gann (1996, p.184); see figure 34, above*

These figures have been changed to cent offsets above/below octave rather than absolute cents values above given lower octave boundaries.

As noted earlier in the chapter in relation to (Young, 1964), a two-dimensional representation which considers consonance/dissonance effects may also offer a potentially useful additional perspective. However, in the case of his installation pieces, it seems reasonable that such a model of consonance/dissonance relates to periodicity rather than critical band response for two reasons. In the first instance, the sustained nature of the presentations should foreground periodicity–based judgements at the relative expense of sensory dissonance based on critical band overlap as the primary factor in consonance/dissonance judgements. In the second instance, the individuation of frequency components which occurs as the result of the direction–dependent head/upper body filtering and location–dependent room acoustic effects is likely to further reduce the relative importance of critical band overlap as a contributor to dissonance judgements. As such, a scale which measures the mathematical complexity of intervals (corresponding to a periodicity–based scale) for the assessment of *relative interval consonance*[130] will be graphed here (figure 36, below, next page).

---

130 As Young assigns 'dissonance' outside the realm of his tunings, to temperaments.

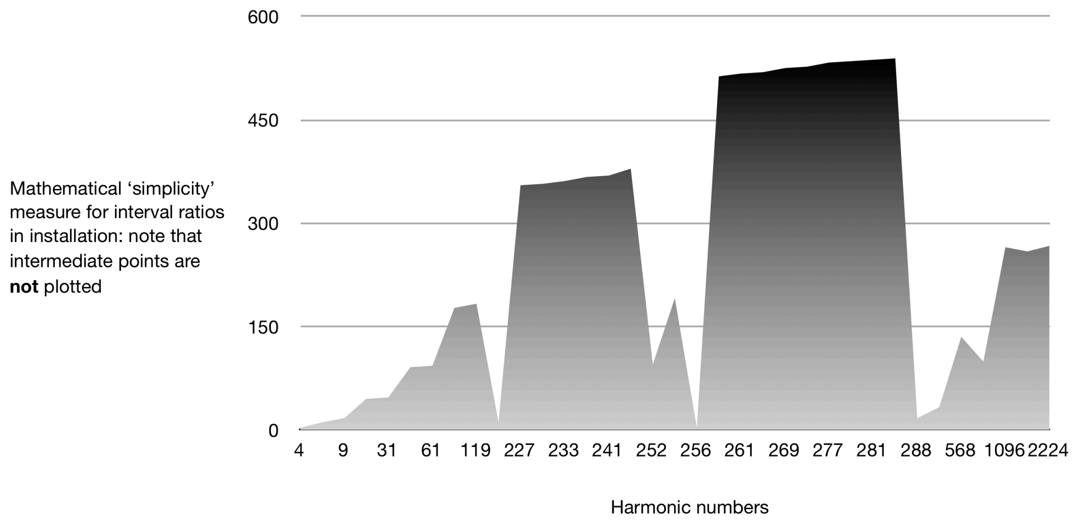


Figure 36: Harmonic intervals from The Base 9:7:4 Symmetry in Prime Time...*(Young, 1991) plotted against an additive measure of ratio simplicity after method outlined in Wishart (1996, pp.71–73) and Loy (2006, pp.57–8)*

Note that in contrast to the plots in Wishart, intermediate points between these main intervals are not graphed; Wishart's intention in plotting intermediate points was to highlight a potential inconsistency in this method when graphing tempered intervals.

The approach used in this graph is termed the *additive dissonance metric* by Loy (2006, p.59) and is obtained by summing the numerator and denominator of the simplest statement of an interval ratio; e.g. 5/4 yields a metric of 5+4=9, 81/64 yields a metric of 81+64=145; thus 81/64 is considered to be significantly more dissonant by this measure than 5/4, even though they are both similar in interval size. Young's view of just intervals with higher additive dissonance metrics as simply being more complex/potentially unfamiliar consonances ameliorates the problematic idea that a major third variant might be dissonant (indeed, as discussed earlier, Young would not regard 5/4 and 81/64 as equivalent identities). With this careful version of a definition, the metric might be better termed an *additive relative consonance-simplicity metric.* Although, as Loy (2006, pp.57–8) points out, this approach 'suffers' from not segregating intervals into consonant and dissonant groupings, when framed in Young's terms this is no longer of relevance (as the only truly dissonant intervals are those described by complex irrational ratios).[131] Loy (*ibid.,* pp.59–60) outlines a solution to the categorisation/segregation issue, a *partitioning dissonance metric* based on prime factors, may be used to segregate integer ratios into consonant and dissonant categories; those based on higher primes being considered to be more dissonant.[132] .

However, such an approach, potentially connected as it is with distinctions in the functionally–based preparations of changes in tonal centre or movement through axes between functional dissonances and consonances, is of little relevance for Young's drone-based approach. Although Young is a 'democratiser' or 'leveller' in terms of eschewing rigid distinctions between consonance and dissonance for integer-based interval ratios, it appears that he nonetheless takes a close interest in their ordering. The symmetrical structuring in terms of interval size is clearly one such feature of his installation work. The additive dissonance metric reveals another aspect of larger-scale structure in (Young, 1994). As can be seen from figure 36 (above) and figure 37 (below, page after next), the two dense clusters on either side of the central octave of the fundamental (256th harmonic) go through processes of increasing monotonically for

---

131 Although this endorsement of this metric is somewhat tautological, based on the arguments above there is no clear reason why it is an inappropriate metric for describing Young's approach; any metric which introduces strict boundaries between consonant and dissonant intervals is incompatible with his approach to interval generation/substitution, such as the treatment of seconds and sevenths for more traditionally consonant intervals (thirds and sixths) in his earliest pieces.

132 This is essentially a restatement of the functionalist prime–limit concept discussed previously; cf. Partch (1974, pp.125–6)

this metric (with the exception of 252 and 254 for the first cluster and 288 at the boundary of the second cluster). In addition, as can be seen from these figures (and figure 31), this installation exhibits its most complex intervals (as well as its greatest intervallic density) in frequency regions which introduce a significant degree of location–dependent or direction–dependent individuation.

Harmonic No.	***Additive relative consonance-simplicty metric***
4	3
7	11
9	17
29	45
31	47
59	91
61	93
113	177
119	183
224	11
227	355
229	357
233	361
239	367
241	369
251	379
252	95
254	191
256	3
257	513
261	517
263	519
269	525
271	527
277	533
279	535
281	537
283	539
288	17
544	33
568	135
1072	99
1096	265
2096	259
2224	267

Figure 37: Harmonic intervals from The Base 9:7:4 Symmetry in Prime Time...*(Young, 1994) listed alongside the additive measure of ratio simplicity after method outlined in Wishart (1996, pp.71–73) and Loy (2006, pp.57–8)*

4.5.5 Transcendentalist Specifications

One curious aspect of Young's later installations, from the point of view of perception, is the use of materials which are at higher frequencies than those associated with the perception of musical pitch. This is a feature in both (Young, 1989) and (Young, 1991). In the former, as can be seen from figure 18, above, intervals of up to the 1009th and 1152nd harmonics above a 7.5 Hz subsonic fundamental are heard, resulting in frequencies of 7567.5 Hz and 8640 Hz. These frequencies are above the level generally associated with clear pitch perception (5 kHz). In the latter (see figure 22, above), a greater number of intervals are to be found above 5 kHz: 1072nd harmonic (8040 Hz), 1096th harmonic (8220 Hz), 2096th harmonic (15720 Hz) and 2224th harmonic (16680 Hz). However, the account in Young (1969), his most extensive exegesis with relevance to his installation work, demonstrates that he is conversant with both place and temporal theories of pitch perception (and the issue of pitch perception abilities becoming attenuated at higher frequencies), so it is safe to conclude that this is no mere oversight. In relation to the frequencies which lie below 10 kHz, a perceptual distinctiveness with regard to their presence is certainly to be found in their location–dependent textural attribute: their presence contributes significantly to direction–dependent filtering effects based, in particular, on the pinnae–derived aspects of the HRTF, as discussed above.[133]

Treating the components which exceed 10 kHz, the presence of these intervals is particularly troublesome when considered solely on the basis of their perceptibility as

[133] The presence of these components is also likely to contribute significantly to a height-based spatial perspective based on a spatial–metaphorical mapping of low–high, with the additional possibility that listeners may experience the presence/absence of these components as evoking a changing elevation and front-back perspective effect through the 'standard' perceptual application of the HRTF–derived cues.

frequencies. In the first instance, they occur in a frequency region where the fine-tuned discrimination abilities associated with pitch are lacking. More fundamentally, and in the second instance, they occur within a frequency region for which the composer himself, in common with many adult humans, may no be longer capable of hearing. As many accounts have pointed out—e.g. Schaefer (1996, p.30)—Young suffers from a degree of hearing loss which may be *noise-induced hearing loss* (NIHL, which may be occupational) exacerbating age-related *presbyacusis* (associated with degeneration); this is generally most marked at higher frequencies.[134]

At the time of composition of this installation, Young (born 1935) was 56, and so may well have had difficulty in distinguishing most of these higher frequency components: the threshold of hearing above 15 kHz is raised for most adults (even young adults) and this effect increases with age (Ashindara et al., 2006, cited in Moore, 2007, p.61).[135] Even leaving aside issues relating to fine-tuned pitch perception, a significant proportion of the adult population (including the composer) will not hear the highest components in the installation. It seems clear in this regard that the composer intends something other than that the frequencies are of direct perceptual relevance. As Gann (1996, p.186) demonstrates, these higher frequencies form part of a symmetrical pattern (the eponymous 'symmetry' of the title) which has a counterpart in a lower–frequency region group below the central cluster (based on the 29th, 31st, 59th, 61st, 113th and

[134] Davis (1995, cited in Moore, 2004, p.61) found in an age-related survey of UK subjects that listeners in the range 71-80 years had significant hearing loss in higher frequency regions (4, 6 and 8 kHz); 81% had a hearing loss greater than 40 dB in this range.

[135] Indeed, the applications of audio-based deterrence units such as the *Mosquito* and the development of digital audio files to act as mobile phone ringtones heard only by younger populations, the *Teen Buzz* ringtone, are based on the principle that older listeners will be unable to detect stimuli at frequencies of circa 16 kHz, even when presented at relatively high SPL values (Howard and Angus, 2009, p.417). These applications make it clear that this type of age-related hearing loss has an early onset for higher frequencies, including those which are deployed in Young's installations.

119th harmonics). These frequency groupings can be seen in the fourth–to–sixth and eighth–to–tenth octaves of figure 18. Thus, the priority for Young in adding these components appears to be the preservation of a strict symmetrical structure in the installation at a formal rather than perceptual level. In effect, this formal integrity is accorded a privileged position over perceptual limitations. In some respects, this is in keeping with his earliest conceptual work. There is, perhaps, an analogical parallel in the visual art prior to the codification of principles for evoking three-dimensional perspective in a two-dimensional drawing: just as pre–Renaissance visual art frequently eschewed even an approximation of linear perspective in favour of what may be considered a more metaphorical 'God's–eye–view' which did not focus on a single (human) viewpoint, the specification of these intervals bears some traces of an omnipotent/transcendental perspective which may owe something to Pythagoreanism and other spiritual/mystical impulses. However, as these components do not contribute directly to perception, any further discussion would not progress our knowledge of the perception and cognition of microtonal materials; Grimshaw (2012) contains extensive discussion of religious/spiritual influences in Young's work.

To conclude, Young's compositional structures enjoy a somewhat distinct existence in the formal domain which is not always directly connected with the perceptual domain. Yet Young is clearly a composer who is more aware than most of issues relating to auditory perception, as evidenced by his longstanding prescriptive conditions regarding amplification levels in presentation and theoretical writings which demonstrate an engagement with auditory perception research as an enrichment of his focussed conceptualism (Young, 1969). His strand of conceptualism is of the Henry Flynt and Fluxus variety; of Fluxus, as Labelle (2006, p.68) puts it, '[t]he Fluxus project and its eccentric *cultivation of singular events* tunes the ear towards acute refinement, *bringing perception and the field of the everyday up against questions of representation and experience*' [italics mine]. Labelle further adds that the concept 'is experienced as an immediate presence—an art that presents to the viewer/listener an experience to be completed through the very act of perception'. Its subject is the particular perceptual case and its resultant experience; to use my own preferred terminology, it is perceptual-conceptualism. The sensuous experience coexists alongside inspiration drawn from rational scientific (and scientistic) modernism which internalises the twin parametric developments of psychoacoustics and musical serialism.

Yet, as can be seen from the issue of the unheard frequencies and pitches, the rationality of the perceptual approach is only partial; an extension of this ethos/principle of rationality in the structural domain requires Young to occasionally depart from the perceptible (and with it, the strictly rational). The rational impulse of symmetrical organisation in his specification of interval ratios leads him to an excess of Pythagorean mysticism by requiring that he work with materials which are either barely perceptible in his domain of primary interest (high frequencies which do not possess clear pitch) or are frequently not perceptible at all to the majority of adults. Thus, the twin interests of the perceptual and the formal are clearly connected, yet somewhat antagonistic, in Young's work. They coexist, but not easily, with results which are not readily predictable in advance, much as the forms which Young deploys often produce unexpected perceptual results.[136]

---

[136] In my own intuitive conception of this relationship, it is difficult to avoid thinking of it in terms of the Yin/Yang symbol of Taoist mysticism.

4.7 James Tenney: American Spectral Music and a Theory of Microtonal Harmony

James Tenney occupied a wide variety of music-related roles throughout his life—composer, researcher into computer music and music theorist—and it is notable that he is grouped by Gann (1996, pp.167–9) with a number of composers investigating the conceptual and structural implications of perceptual phenomena under the rubric *Post-Cage Conceptualism*. Tenney's investigation of the harmonic series is most relevant for the present account, combined with a position which follows that of Johnston in believing that what they viewed as the crisis regarding the exhausted common practice syntaxes for pitched materials in twentieth–century music could only be solved through the deployment of microtonal divisions (Gann, 1996, p.169). The compositional fruits of these concerns encompasses much of his output since the early 1970s, including his *Spectral CANON for CONLON Nancarrow* (Tenney, 1974), his *Harmonium* series from the 1970s, *Critical Band* (Tenney 1988b) and the *Spectrum* series (1995–2001). In the theoretical domain, an account of some of his ideas regarding harmony can be found in the essay 'John Cage and the Theory of Harmony' (Tenney, 1983), in addition to discussions in a variety of interviews including (Tenney and Belet, 1987; Tenney in Gagne, 1993; Tenney, 2008). However, as Gilmore observes, some of Harry Partch's (and Ben Johnston's) conceptions regarding ratio-based organisation provide as much (if not more) of a basis for Tenney's theories than those of John Cage, even if Cage provides some conceptual and creative inspiration and support through a more general understanding of his aforementioned experimental ethos (Gilmore, 1995, p.485).

However, consistent with a Cageian position of a conceptualism allied with ‘perceptualism’, Tenney’s consideration of the harmonic series in nature and in human perception is arguably the most fundamental foundation of his ideas regarding harmony:

> I've always been fascinated by the sheer acoustical and psychoacoustical fact [...] that the auditory system integrates what, from an acoustical standpoint, is a complex set of frequencies. For one reason or another—and this is an extremely important theoretical question as far as harmony is concerned—the auditory system is able to integrate that complex set into a single percept. And I think it's quite possible that just thinking about that, I began to think of it as a possibility for compositional integration. The whole interplay between multiplicity and singularity, complexity and simplicity, began to interest me.
>
> (Tenney, quoted in Gagne, 1993, p.393)

Thus, the harmonic series as structure is a key foundational principle in Tenney’s investigation of just intonation and his conceptualisation of pitch–space is fundamentally derived from this structure in terms of the perceptual interplay between grouped and individuated sonorities. This direct incorporation of the harmonic series as compositional structure and structural philosophy thus marks Tenney's ideas as somewhat distinct from the structural models of Partch and Johnston and perhaps owes more to Cage's general direction that ‘the function of Art is to imitate Nature in her manner of operation’ (Cage, 1968, p.31), if we agree with the (persuasive) interpretation of Emmerson (2007, p.13) that this involves an examination of structural principles rather than the simple incorporation of ‘real world sounds’. In addition, in functional terms, Tenney appears to share Johnston’s ideas concerning extended functional relationships:

> In my view Western tonality is some subset of a larger set of harmonic

> possibilities. And what I'm interested in doing is trying to explore that larger set and not fall back on common-practice harmony. (Tenney, 2008, p.88)

However, he also appears to be aware of a tendency to gravitate towards structures derived from the earlier intervals of the harmonic series (with the implication that there is some limiting factor in terms of the scope of the aforementioned 'larger set'):

> But you can't avoid the fact that our hearing relates to that structure in a certain very special way. I mean, tonality, you could say, is based on the first six harmonics, more or less.
>
> (Tenney, 2008, p.88)

As such, the harmonic series becomes *both* a scale form *and* a potential set of functional relationships, occupying a privileged position with respect to the specification of such relationships. In establishing this as his structural (and philosophical) focus, as Wannamaker (2008, p.92) has noted, Tenney's work bears some resemblance to that of the European spectral 'school' of composition[137] which bases structural configurations on equal temperament approximations of spectra obtained from analyses of (generally) harmonic instrumental timbres. Indeed, Wannamaker (p.123) goes further and suggests that Tenney is a member of a distinctive American variant of spectral music along with Alvin Lucier, La Monte Young, Phil Niblock and Glenn Branca, amongst others.

In proposing his main premise of structural and stylistic similarity between the American and European practitioners, Wannamaker (pp.91–2) summarises a number of common features of spectral music, a number of which can clearly be seen to mirror

---

[137] See Fineberg (2000a, pp.1–3) and Anderson (2000, pp.12–21) for general coverage of the historical and stylistic development of European spectral music; see Féron (2011) for coverage of the early formative influences of spectral models on Grisey's music.

many of Tenney's concerns: e.g. a focus on 'the perceptual duality of harmony and timbre' and the more general investigation of musical applications of psychoacoustic phenomena, beyond the presence of harmonic–series–derived structures. However, even in this analysis, Tenney's approach (and those of the other Americans noted above)[138] is somewhat distinct: it involves an ideal harmonic series structure being applied to musical materials rather than materials derived from spectral analyses of instrumental tones and approximated through tempered microtonal divisions (Tenney, 2008, pp.82,87). With regard to comparisons with 'orthodox' spectral music, Tenney (p.83) has noted that the tempered approximations present in much European spectral music are too inexact for his purposes[139] and he discerns the presentation of dialectical forms in some (unspecified) spectral pieces which conflict with his preferences for conceptual/formal simplicity or, as he puts it, 'elegance' in a 'mathematical sense', whereby his pieces provide very singular explorations of given phenomena. However, the other attributes of his approach, including the use of the harmonic series and the aforementioned interest in structures which occupy equivocal positions between harmonies and timbres provide evidence of sufficient common ground to make Tenney a reasonable candidate for a somewhat distinct American strand of spectral music which nonetheless shares some philosophical (and structural) common ground with its European counterpart. Wannamaker's (2008, pp.94–103) in-depth analyses of a range of Tenney's pieces bears this out, whilst also discerning some differences, such as 'stricter

---

[138] Although Lucier and Niblock engage with harmonic series structures through the exploration of combinations of musical materials which engender psychoacoustic phenomena, producing perceptible harmonic series structures through their interaction. The results of following the instructions in La Monte Young's *Composition 1960 #7* also engage with a similar means of production of perceptually-segregated harmonic series materials.

[139] Even if precompositional structures in much European spectral music utilise more precise tunings before approximation (Fineberg 2000b, p.84), Tenney has a more direct concern for the integrity of pure tunings which may preserve some degree of finer intervallic distinction through more accurate approximations.

intonation, a focus on harmonic series structures to the exclusion of some of the inharmonic spectra found in European spectralism' and 'a relative exclusion of textural variety and formal elaboration' (*ibid.,* p.103). Thus, the ideal harmonic series is an even more privileged structural imperative in Tenney's music than it is in European spectral music.

4.8 Tenney, Cage and a Perceptually–grounded Theory of Harmony

Tenney's interest in the harmonic series as a structure reflects a wider interest in the connection between perception and cognition and musical practice, which had previously led him to consider applying principles derived from Gestalt psychology to music[140] (Tenney, 1964/1986). In combination with the formative influence provided by Cage in terms of the exhortation to engage in a more empirically based musical practice, Gestalt concerns relating to grouping and segregation in perception can be seen as providing a foundation for Tenney's expanded theory of harmony as extended from a 'challenge' provided by John Cage's concept of *aggregates*:

> . . . a static gamut of sounds is presented, no two octaves repeating relations. However, one could hear interesting differences between certain of these sounds. On depressing a key, sometimes a single frequency was heard. In other cases . . . an interval [i.e. a dyad]; in still others *an aggregate of pitches and timbre*s. (Cage, 1958a, quoted in Tenney, 1983, p.15)

[140] It is interesting to note that Tenney's original engagement with this area predates the extensive empirically-based research programme of Albert Bregman from the early 1970s, culminating in the publication of Bregman's monograph which developed a theoretical framework to explain his findings, part of which addressed musical organisation in addition to general auditory perception (Bregman, 1990).

[Italics Tenney's]

Tenney views the question of the conditions under which auditory perception and cognition groups and segregates material as of key importance for an expanded and descriptive (as opposed to pre–/proscriptive) theory of harmony (*ibid.,* pp.3,15). In particular, he regards the conditions of grouping and segregation for harmonic tones as providing important evidence towards a more generalised account of harmonic organisational possibilities:

> [U]nder what conditions will a multiplicity of elementary acoustic signals be perceived as a 'single sound'? When this question is asked about a compound tone containing several harmonic partials, its relevance to the problems of harmony becomes immediately evident.
>
> (Tenney, 1983, p.15)

This interest in the auditory perception of harmonic series materials is, as noted above, a concern held in common with European spectralism; here, Tenney suggests that this interest in the harmonic series (and questions of perception in general) can be extended into a more general perceptually-grounded theory of harmony.

4.8.1 A History and Definition of 'Harmony' and the 'Consonance-Dissonance Concept'

In seeking to develop a more comprehensive theory of harmony, Tenney engages in a critical analysis of the use of the term to describe various historical practices, seeking to redefine it in a manner which will not provide a barrier to Cage–influenced theorising (*ibid.,* p.19). What follows is an early presentation of materials later developed in his monograph on the semantic history of 'consonance' and 'dissonance' in Western musical discourse (Tenney, 1988). Although in more recent common usage, harmony implies the relationship between components of a simultaneous sonority, Tenney reminds us that the initial Pythagorean conception related to non-simultaneous (thus, functional) 'relations between pitches' (Tenney, 1983, p.19). He notes that this conception of harmony persisted until the medieval period, with the shift to a meaning involving simultaneous or ‘vertical’ sonorities happening alongside the beginnings of polyphonic musical practice (*ibid.,* p.20). Tenney (1988, pp.9–16) terms the Pythagorean conception of harmony *consonance/dissonance–concept–1* or *CDC–1*. In *CDC–2* of the early polyphonic era, consonance/dissonance is related to the presence or lack of tonal fusion in simultaneous sonorities (Tenney, 1988, pp.17–31). The subsequent *CDC–3,* concerning the counterpoint of the Renaissance and Baroque eras, reinstates what might be viewed as functional concerns with regard to the component melodic lines involved, in addition to some extra concern for more immediate sensory issues, such as specification regarding registral spacing to enhance clarity (*ibid.,* pp.39–58). The Classical/Romantic *CDC–4* sees consonance as a product of the ‘perceptual stability of a triadic component’, with perceptual here actually referring to higher-level (and less immediate) cognitive judgements (pp.65–86); this conception prioritises the functional component within harmony:

> [I]n CDC–4, dissonance is no longer the “result” of melodic motion, but one of its primary *causes*. In addition, this association of dissonance with motion gradually begins to reflect back on the consonance/dissonance concept [...] if a note is judged to have a strong tendency towards motion—for whatever reason—it may therefore come to be called ‘dissonant’. (*ibid.*, p.78) [italics Tenney]

Overlaid upon this is the post-Helmholtz psychoacoustical view (CDC–5) of consonance as related to a lack of sensory dissonance due to the critical band response of the basilar membrane (*ibid.,* pp.87-94).

For the present purposes, the crucial aspect of Tenney's investigation of changing definitions relating to harmony provides a helpful delineation of two component meanings within what may be an 'umbrella' term: meanings related to sensory consonance and dissonance (i.e. the momentary perception of simultaneous sonorities) and the more indirect experience of cognitive/formal/functional relations between materials which are not *necessarily* simultaneous. For Tenney, structural (functional or formal) inspiration is derived from the harmonic series as both physical and perceptual phenomenon. But the more proscriptive treatment of sensory consonance/dissonance judgements appears to be crucially absent; he opines that the 'two most important problems in earlier harmonic theory—regarding the nature of consonance and dissonance' may be of less import to future theorists (Tenney, 1983, p.32). I take Tenney's implicit meaning here to be that a simple oppositional framework of consonance/dissonance may give way to more subtle gradations characterising sonorous and formal relationships between notes, with a wider range of formal possibilities opening up through the provision of a more expansive framework for the connection of source materials including microtonal divisions. In relation to a more positive generalised description of the consonance/dissonance phenomena, Tenney presents a Johnston–and–Partch-influenced geometric representation of *harmonic space*, which he asserts is largely descriptive of the relations between materials and consonance/dissonance judgments in previous theoretical assessments:

> [T]here is one simple generalization that can be applied to nearly all of these different conceptions of consonance and dissonance, which is that tones represented by proximate points in harmonic space tend to be heard as being in a consonant relation to each other, while tones represented by more widely

> separated points are heard as mutually dissonant. Now this statement serves neither to clarify the distinctions between different senses of consonance and dissonance mentioned above nor to 'explain' any one of them. It does, however, indicate an important correlation between consonance and dissonance and what I am calling harmonic space. (*ibid.*, pp.32–3)

An earlier invocation of Schoenberg regarding the idea that consonance and dissonance are grounded in comprehensibility would seem to corroborate this position, which might be termed a 'weak functionalism', whereby the functional relationship may or may not be directly related to cognitive judgments on the basis of a formal mapping of pitch space, but which, at the very least, provides a formal *representation* of consonance/dissonance relationships and may provide a model with some similarities to the cognitive model used in judgments of consonance and dissonance in non-simultaneous contacts. Tenney states that Cage may have been closer than he realised to Schoenberg's theoretical position regarding definitions of consonance and dissonance:

> What distinguishes dissonances from consonances is not a greater or lesser degree of beauty, but a greater or lesser degree of comprehensibility . . . The term emancipation of the dissonance refers to [this] comprehensibility . . .
>
> (Schoenberg, 1913, cited in *ibid.*, pp.17–18)

In invoking a putative Cageian sympathy for this sentiment, Tenney himself places 'comprehensibility' at the centre of a theory of consonance and dissonance within harmony. Taken together, these quotes seem to imply that the formal/functional structuring impulse may be somewhat in the ascendent in Tenney's view. However, this functionalism is still tempered by a philosophy of 'perceptualism'. Such a position may be conceivable through the inspiration for his functionalism lying largely within the harmonic series as a model for a set of formal relations (or cognitive structure) derived from an environmental phenomenon:

> I'm using it [ie. the harmonic series] because of its special properties or the special properties of the auditory system in relation to it. It's a unifying structure. It's a structure that our auditory systems have built into them: the capacity to reduce to a unity, to a singularity [...] And that's a very useful formal idea. And I try to take advantage of that, formally—to use it so there is that sense of coming into a higher degree of unification.
>
> (Tenney, 2008, p.87)
>
> [I]t is the nature of harmonic perception in the auditory system which 'explains' the unique perceptual character of the harmonic series, not [...] the other way around. The harmonic series is not so much a causal factor in harmonic perception as it is a physical manifestation of a principle which is also manifested (though somewhat differently) in harmonic perception. (Tenney, 1983, p.34)

However, the idea of the harmonic series as a single instance of a more general structural type and basis for the use of the undertone as well as overtone series to describe musical relationships is not one to which he subscribed, in contrast to Partch and Johnston (Gilmore, 1995, p.488). In addition, his views in relation to conceptual and formal unity provide some degree of priority for a holistic idea of the series as a unifying basis, which underpins his frequent spectralist deployment of a large number of intervals from the series in direct harmonic series ordering, as is the case with *Spectral CANON for CONLON Nancarrow* (Tenney, 1974). Gilmore (1995, p.492) notes that this type of usage is one of two models for pitch structure in Tenney's work, the other being his concept of 'harmonic space'. Such holistic usage is in keeping with his ideas surrounding *ergodic* forms, those which are 'statistically homogenous at some hierarchical level of formal perception' (Tenney, 1983, p.14) and his dislike of more traditional dialectical forms (Tenney, 2008, p.83).

4.8.2 Tenney's Formal Model of Harmonic Structures

Beyond the simple concept of the harmonic series as a unifying element in pitch structuring, Tenney's ratio–based model of *harmonic space* provides a formal framework for the pitch relationships. Such a model arguably contains elements of his CDC-4 (in terms of a primacy of functional/formal relations) and CDC-5 definitions of harmony (the latter due to the rough correspondence between simple integer ratios and the occurrence of sensory consonance relating to a lack of audible beating due to a preponderance of coincident harmonics). Although Tenney's geometric representation of harmony does not take precise account of issues regarding sonority and register (relating to the critical band response) and limits in discriminability and perception and cognition of pitch categories, he does provide something of an analogue for these issues through his application of the idea of *tolerance* to the ratio model (Tenney, 1983, pp.22–3).[141] Given the aforementioned influence of psychology on Tenney's theorising, it is no surprise that he does not take the numerical distinctiveness of ratios to mean that a given interval is necessarily salient. In discussing an extension of the geometric pitch representations of Partch and Johnston, he notes the implications of adding each prime successive prime factor to a representation of ratio–based relationships: another dimension would be added (*ibid.*). Thus, 3–limit (Pythagorean) pitches can be represented in a harmonic space created by transpositions of fifths (3/2), fourths (4/3)

[141] This concept of tolerance is similar to Fokker's *unison vector* concept; see chapter two for a brief account in relation to Fokker (1969) and Erlich (1999).

and octaves (2/1), resulting in two dimensions: the dimension involving powers of 3 (fifths and fourths) and the dimension involving powers of 2 (octave relations). He also expands upon this to note that 5–limit just intonation implies a three-dimensional representation for powers of 2, 3 and 5; 7–limit would require four dimensions for powers of 2, 3, 5 and 7 based on this approach (*ibid*., p.23). However, as noted in chapter three in relation to the graphical representation of Johnston's pitch–space[142], this dimensionality can be reduced through removing the 2-based dimension due to octave equivalence (see figure 38, below, following page).

---

[142] See figure 27—after Gilmore (1995, p.482)—in chapter three.

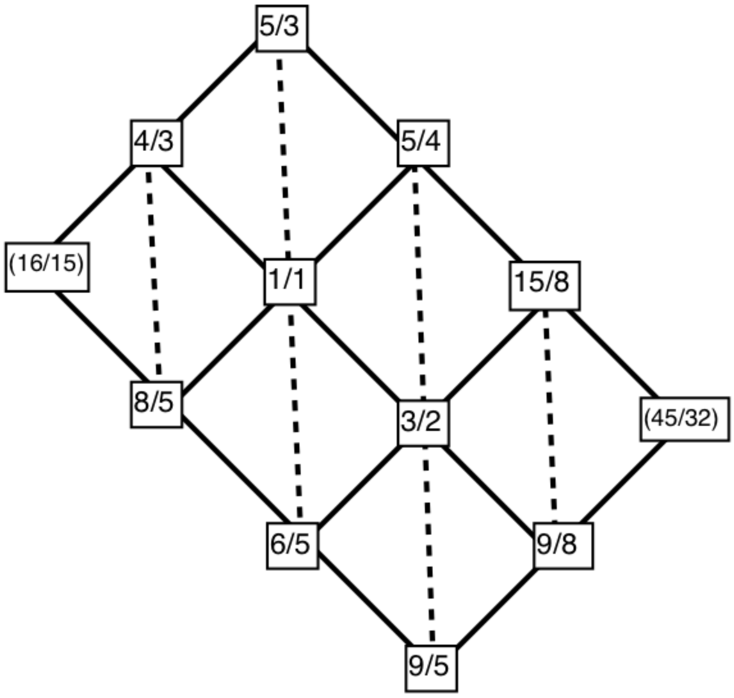


Figure 38: Two–dimensional representation of primary harmonic relations in the standard 5–limit scale, after Tenney (1983, p.28)

Diagonal top-left to lower-right: 3-based relationships (3/2 fifths). Diagonal top-right to lower-left: 5-based relationships (5/4 major thirds). Dotted vertical lines (not main axis of representation) illustrate 6/5 minor third and major sixth relationships between intervallic nodes.

Another type of reduction comes when the concept of tolerance is initially applied when he notes that the five dimensions of a Partchian 11–limit scale might be reduced if some of the 11–limit intervals were indistinguishable (in perceptual and/or cognitive terms) from those based on lower primes, a principle which prevents what he terms an 'unlimited proliferation of dimensions in harmonic space', noting that this may occur at (unspecified) higher prime limits (*ibid.,* p.23). Thus, Tenney embraces some aspects of the Partch–Johnston pitch model whilst at the same time anticipating limitations which may be placed upon it. Within this construction of harmonic space, the definition of an interval based on the ratio model is refined to 'an interval is represented by the simplest ratio within the tolerance range around its actual relative frequencies, and any measure on the interval is the measure on that simplest ratio' (*ibid.,* p.25), although the the degree of tolerance and the mechanism behind it are not discussed. Nonetheless, this refinement does provide a significant improvement upon the post–Pythagorean assumption that numerical distinctiveness necessarily equates with perceptual and cognitive distinctiveness and thus provides a framework by which limits of perceptiblilty in microtonal materials may be addressed. In addition, another means by which the degree of multidimensionality can be reduced is through removing the representation of octave distinctions and applying the principle of *octave equivalence*, whereby octave transpositions are taken to be identical, resulting in a focus on *pitch-classes* within a generalised octave (*ibid.*) and providing a more compact representation of relationships.

4.8.3 Microtonal Harmony and Models of Perception and Cognition

Tenney's justification of microtonality in terms of a more accurate rendering of just–intonation–based intervals is presented using his concept of tolerance:

> In representing what has become an equally tempered version of this chromatic scale with low-integer ratios in harmonic space we implicitly assume a fairly large tolerance range (on the order of 15 cents or more), but this is precisely what is implied by the use of our tempered scale for triadic/tonal music. Thus it is no wonder that the evolution of harmony as a clearly functional force in Western music reached a *cul de sac* around 1910. New compositional approaches to harmony will almost certainly involve new "microtonal" scales and tuning systems, and this model of harmonic space provides a useful tool for the design of such systems, as well as for the analysis of old ones. (Tenney, 1983, p.28)

Thus, this representation of functional relationships (based on the psychophysical phenomenon of the harmonic series) is used to justify the concern for accurate tuning which functionalism usually implies (e.g. in the tempered context which he mentions), effectively turning the more usual argument relating to functionalism and interval-tuning relativism on its head. The argument that the tolerance range used in the more traditional conception of harmonic space is relatively large implies that new functional relationships may be created through the application of more accurate tuning and a formal framework which matches greater accuracy of pitch specification (distinct microtonal intervals) with each new dimension describing a particular type of functional relationship.

Tenney goes on to suggest that the absolute dimension (pitch–height) has a 'physiological correlate in the basilar membrane' and that the pitch–class–based harmonic space has an existence in pitch-processing centres of the central nervous system and more sophisticated cognitive processing utilising short–term memory (p.29), though he does not specifically cite any research related to divisions between cognitive and psychoacoustic approaches to pitch, such as Shepard (1964, p.2351; 1982, pp.306–9). Nonetheless, the invocation of such issues (and the mention that short–term memory may play a role in such processing) raises some difficult questions for microtonal practice relating to short–term memory capacity. For the present purposes, however, Tenney's work can be clearly seen as an attempt to develop a music–based theory for expanded harmonic relations and frame it in a manner which may facilitate a dialogue with psychology regarding a unified theory of harmony which could serve both fields.

An elaboration is presented in relation to the nodal points in this harmonic space: they are activated only when a corresponding point in the pitch–height space is activated, with such activations only happening after a pitch has been present with a degree of stability (and perceptual salience) for more than a short period of time, which Tenney suggests as more than a few hundredths of a second (Tenney, 1983, p.29). He further suggests a persistence in activation of this node over a longer period of time through the action of holding such information in short–term memory, providing for functional relationships (p.30). A more radical proposition is to be found in his suggestion regarding the grouping of components:

> a multiplicity of elementary acoustic signals will be perceived as a 'single

> sound' — even long after the initial onset — when their images form a cluster of contiguous points either in harmonic space or on the pitch-height projection axis alone. (Tenney, 1983, p.30)

Tenney does not immediately unpack the possible differences in cases provided by the two distinct mechanisms (one would arguably be redundant if there was no difference in its applicability). However, the somewhat implicit meaning here is that the more sophisticated cognitive grouping describes some aspects of grouping of components of an auditory 'scene', such as the grouping of notes in a chord, as an elaboration of grouping based on the psychophysical pitch–height axis, a meaning which is subsequently made more explicit through the following (closing) statement:

> The harmonic series is not so much a causal factor in harmonic perception as it is a physical manifestation of a principle which is also manifested (though somewhat differently) in harmonic perception. That principle involves the mutual compatibility—as elements in a unitary gestalt or "system" (whether physical–acoustical or psychoacoustical)—of frequencies exhibiting certain rational relations to each other. (Tenney, 1983, p.34)

This provides a more nuanced version of the commonplace assumption that chordal grouping is in some way related to the grouping together of harmonic partials with synchronised onset times. In effect, this idea suggests that there may be a process which is not completely simple or 'mechanistic' at play in pitch/frequency-based grouping.

This suggestion may be further corroborated in cases of perceptual grouping for single sound sources with incremental degrees of spectral 'stretch', that is, a small, regular and progressive increase in spacing between successive partials, as investigated by Roberts and Brunstrom (1998, 2001), leading to the suggestion of some sort of regularity of pattern rather than the harmonic series *per se* creating the conditions for perceptual grouping of simultaneous components.[143] Such a process would corroborate Tenney's aforementioned intuition that the harmonic series itself is a special case from a generalised psychophysical or cognitive phenomenon; one based on more widely-applicable regularity of patterning would undoubtedly be of greater ecological utility. If such a generalised process is at play, perhaps a more advanced cognitive analogue or counterpart process would also provide for the significant degree of tolerance which Tenney's model discerns in a 5–limit harmonic framework rendered in 12TET divisions.

Perhaps a generalised statement of Tenney's framework is that a point in harmonic space is produced by a relatively stable pitch percept which is translated from absolute pitch-height to pitch–class within an octave, with quantisation to a nodal point based on an unspecified tolerance mechanism. However, such a pitch still operates within a functional framework which can be described numerically by a framework of integer ratios, even if the heard pitch deviates somewhat from this idealised framework. Furthermore, an increase in the number of functional relationships may be provided by the deployment of higher prime factors, to an unspecified limit, and these higher-prime-based ratios may introduce microtonal subdivisions of previous pitch categories which may facilitate an extension of functional harmony. The sensory and cognitive basis of this process is somewhat unclear, but the commonplace idea regarding a relatively robust syntax of pitch-space relations which underpins much Western music theory suggests that such a cognitive representation is present and simple integer ratios seem to

[143] Following these and other findings, Roberts and Brunstrom (1998) proposed that the computation of global pitch and spectral fusion may be the subject of separate processes.

provide some sort of prototype for a variety of functional relationships (perhaps related to their perceptual i.e. sensory distinctiveness, as found in the dissonance plots of Harry Partch and Plomp and Levelt). However, whatever the explanation, Tenney’s suggestion of a generalised theory of harmony inspired in part by his own experience as a microtonalist certainly moves the debate on from the more sensory-based argument of Partch[144] to a more syntactically–grounded explanation, providing a modification of Johnston's model which would allow for its extension and refinement as the field of psychology advances, whilst being provisionally underpinned by Tenney's speculation informed by his knowledge of both contemporary composition and psychology.

One particular point of comparison with Partch's ideas relates to Tenney's concept of tolerance–limited functionalism which, in spite of the similarities to Partch’s formal schemata found in the tonality diamonds, may differ somewhat from Partch’s ideas regarding some microtonal intervals as colouristic variations of interval types; cf. Partch (1940, p.159). This conception is not really made explicit in Partch’s subsequent theorising, but Tenney’s tolerance-limited functionalism is arguably a little antithetical to the focus on sonority rather than function which Partch appears to espouse here as a motivation for the deployment of microtonal materials. Partch’s philosophical attachment to the sensory effect over an elaborate functional model is perhaps the main reason why, in spite of the antecedent common ground found in its ratio representation, Tenney, as noted above, regards Partch's work as an influential but incomplete step in the extension of the challenge of just-intonation-based microtonality to functional

[144] Tenney (quoted in Gilmore, 1995, p.484) spoke of Partch's contribution as follows: 'I now see his theoretical work… not as a complete theory of harmony or harmonic perception (or certainly not as a sufficient one), but as perhaps the most important of a small number of 20th-century contributions toward the development of such a theory.'

harmony. Tenney is, in this analysis, a measured microtonalist whose investigations of harmonic space are tempered by the tolerance model, often resulting in the use of 'more compact' representations of intervals in 5–limit or 7–limit rather than using higher prime factors (Gilmore, 1995, pp.487–8).

However, in some cases, Tenney's materials make use of models which *do* favour higher prime limits, albeit in approximations of 1/6th semitones (72TET), such as the suite *Changes: Sixty-four Studies for Six Harps* (Tenney, 1985). Gilmore (1995, p.491–3) notes that this series utilises an 11–limit framework for its tempered approximations, though as he further notes, many sections do tend towards a compact model of pitches using lower prime limits (and dimensions), such as the first study in the series, which utilises a framework of intervals, some of which may be thought of in strict just intonation as being spelled using either 7–limit or 5–limit (a tritone spelt as 7/5 or 45/32) [145]; Gilmore assumes the more parsimonious[146] 5–limit framework for the most part, although some implied 7–limit intervals occur separately (7/4 and 21/16); see figure 39, below, following page.

[145] Tenney's use of intervals which are close to established scale categories and provide functional equivalents provide something of a challenge to the idea of their presence as microtonal categories; it might be argued that such usage would be better classed as alternative tuning of these intervals. However, these intervals, when not viewed in isolation, can be viewed as possessing a functional distinctiveness in comparison with 12TET approximations when examined through the framework of Tenney's multidimensional harmonic space, though in this case, the tendency towards the 5-limit which Gilmore discerns may mean that our strict definition of microtonality from the introductory chapter would be problematic in respect of these materials. However, the 7-limit materials noted below would provide enough functional and sonorous distinctiveness under this admittedly strict definition.

[146] In the general English–language sense of the word, rather than any specifically musical usage relating to voice leading principles.

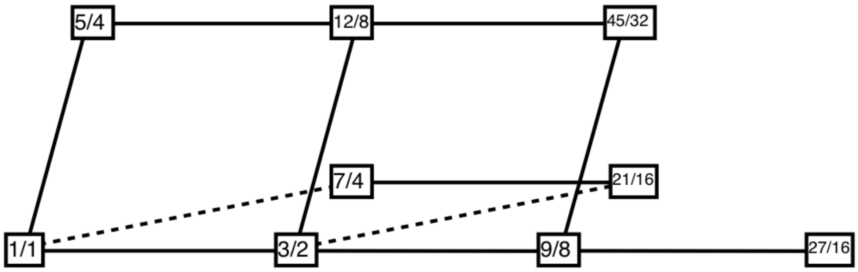


Figure 39: Three-dimensional harmonic space representation of section from Study No. 1 *of Changes (Tenney, 1985), diagram after Gilmore (1995, p.493)*

For clarity, 7-limit relationships are indicated using dotted lines.

Tenney's chamber work *Critical Band* for sixteen or more sustaining instruments (Tenney, 1988b/2001) takes another approach to tuning which utilises a model derived in part (perceptually) from psychoacoustics and in part (formally) from a concept in ancient Greek music theory which results in the deployment of extremely high prime number factors of intervals. As Gann (1997, p.169) has put it with great descriptive accuracy, *Critical Band,* in common with *Spectral CANON for CONLON Nancarrow*, ‘unfold[s] the harmonic series like a flower opening up in the ear.’ The title derives from the proliferation of microtonal intervals which are increments within the range of the ear's critical band response (i.e. approximately a minor third in the mid-range that pitches are taken from in this instance). The pitch materials themselves are derived from the ancient Greek theoretical procedure of obtaining a *harmonic mean* (after Archytas) which is given by the following formula:

$$H = \frac{2ab}{(a+b)}$$

The following account of the harmonic mean follows Crocker (1964, pp.326–9), who notes that when subdividing an interval such as an octave to produce an intermediary step between tonic and octave, another mean, the ‘obvious’ procedure of obtaining the subdivision by dividing a frequency ratio (or string length) in half, described by the geometric mean $G=\sqrt{(ab)}$, would not produce a rational result (hence would not comply with the basic Pythagorean principle of using integer ratios). However, an arithmetic mean $A=(a+b)/2$ would produce ratios which were based on small integers but would still produce *almost* equal divisions of the octave, with 4/3 and 3/2. Such a process produced a useful result in Pythagoean terms for the division of the octave into the next two consonances, the 3/2 fifth and 4/3 fourth, that is 2:3:4 to establish a relationship between the octave, fifth and fourth. However, another mean—the harmonic mean—produces the same ratios as the arithmetic mean, but with a different ordering, which places the fourth before the fifth, thus proceding in order of interval size (p.329). The octave can be expressed as 12/6 (or 6:12 as a string length ratio) and produces an arithmetic mean 9 and harmonic mean 8 (see formulae above). Thus, the arithmetic mean produces a set of ratios of 6:9:12 to describe the division of the octave, simplifying to 2:3:4 (4/2 octave, 3/2 fifth, 4/3 fourth). The harmonic mean produces the ratios 6:8:12, simplifying to 3:4:6, producing the same set of relationships in a different order (6/3 octave, 4/3 fourth, 6/4 fifth);(p.329), with the fourth and fifth in an ordering based on interval size rather than interval simplicity.

This general procedure was thus used to produce non–tempered subdivisions of given intervals in the process of scale construction. In *Critical Band* (Tenney, 1988b), the process is used to create the microtonal pitch materials. Gilmore (1995, p.494) describes the start of this process whereby a harmonic mean is defined and forms a series of ratios which become pairs of intervals held against a tonic (figure 40, next page). The first new interval is 129/128, which has a harmonic mean relationship with 65/64, which is the next main entry (128:129:130, with 130 simplifying to 65/64). The 129/128 interval is paired with an interval from a similar process of descending intervallic pairs (127/128, 63/64, 15/16, 7/8), although the lower pitches in a given section are not introduced until the upper ones have been sounded, based on Tenney's directions for this somewhat modular score. A reduction of the first 9'30 of Tenney's score can be seen below, featuring the interval ratios for each successive 'module'. As Gilmore notes (*ibid.*), following this opening section, the process returns to a more usual generation of material using intervals of increasing size drawn directly from the harmonic series (in ascending and descending form).

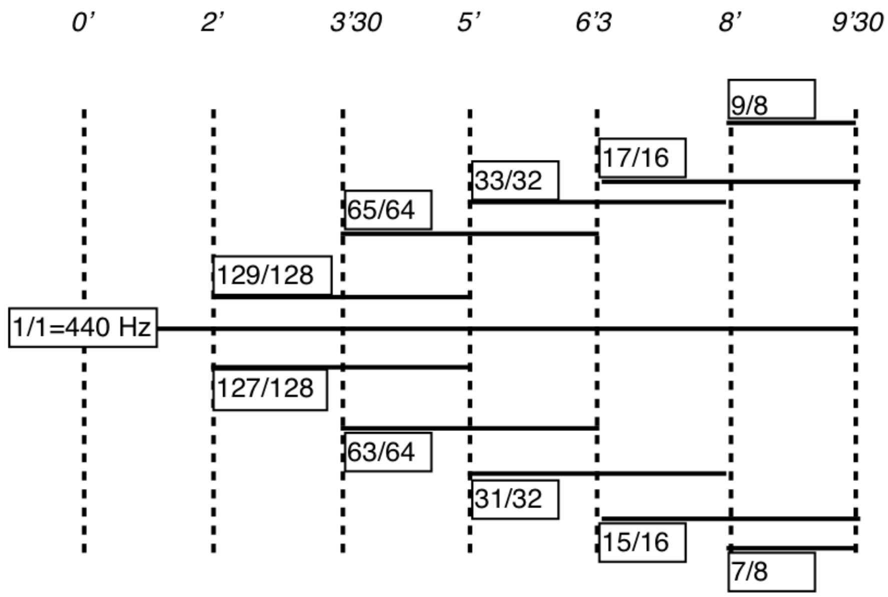


Figure 40: Frequency ratio reduction of the first half of Critical Band *(Tenney, 1988b/2001)*

This representation illuminates the symmetrical nature of its procedural basis which diverges from the relatively complex set of functional relationships previously posited for harmonic space (Tenney, 1984) in favour of one which is based on a simpler 'relationship space' derived from the harmonic series.

However, this piece clearly uses a somewhat different, more aurally–based model than Tenney's harmonic space idea, as can be seen in the use of high primes such as 127, 31 and 17. On this basis, I differ with Gilmore's (p.494) invocation of the aforementioned *harmonic space* concept, even if Gilmore is using it in the most general of terms, as it risks an association with the more formal/cognitive logic of (Tenney, 1983), just as its use of larger prime numbers is in direct conflict with the concept of tolerance–limited ratios. I would prefer to consider *Critical Band* on the basis of a sensory–based (i.e. psychoacoustical) model, which specifies its materials using the language of interval ratios but whose salient structure derives from the harmonic series structure as mediated through the critical band response. The most viable model of pitch-space in this piece is clearly that of the one–dimensional pitch-height axis of the basilar membrane and the similarly one–dimensional vertical structure provided by an essentially scalar logic found in its largely symmetrical unfolding. Rather than a sophisticated cognitive model of pitch relationships, the model here is an ecological recourse to the harmonic series as a physical form upon which a congruent psychological model is based.

In addition, this piece appears to me to be an exploration of an intermediate state between complete consonance and dissonance created through the conditions of sustained tones in microtonal relations with each other effecting an extended degree of segregation of some harmonic components through beating effects interrupting the continuity whereby Bregman's *old–plus–new heuristic* operates, resulting in a more transparent texture than might be expected when noting the clusters present in the score.[147] As such, this perceptual segregation of some harmonic partials from within the initially homogenous sound mass which begins the piece explores an intermediary form of sensory consonance in materials which create overlaps within a critical band on the basilar membrane. The sensory/psychoacoustical CDC-5 model which is applied here is arguably being used to emphasise sensory consonance/dissonance as a Reich-style 'gradual process'; Tenney has previously expressed a preference for this type of

---

[147] This type of aural organisation also underpins the music of Phil Niblock, mentioned at the start of this section.

organisation (see below and previous comments regarding dialectical structures):

> What I'm composing is the larger level. And I'm interested in the larger level. I think I was influenced by Steve Reich in that. I liked those early pieces that had that kind of continuous process aspect to them. (Tenney, 2008, p.84)

Although there is a noticeable change at 9'30", as larger just-tuned ratios begin to enter, the change is in some senses one of degree, as the sustained cluster of intervals within a major second are still present at the centre of the sound-mass (continuing from the 8'00" mark illustrated above for another five minutes or so) and so what would traditionally be thought of as dissonant combinations are clearly coexisting with more traditionally consonant forms.

Thus, even as Tenney (1983) presents a new theory of functional harmony and (Tenney, 1988) interrogates the history of consonance/dissonance concepts, *Critical Band* (Tenney, 1998b) presents a hybrid form of sensory consonance/disonance and pitch–based textural organisation based on an elegant use of a psychoacoustical model. As such, it is my contention that through it Tenney provides an approach to the structuring of microtonal materials which, for all that it is not directly related to his concept of harmonic space, is in fact as compelling a model for some microtonal configurations. If Tenney (1983) provides a provocative theory of functional harmony, *Critical Band* (Tenney 1998b) provides a study in sonority which creatively problematises the functional approach of his earlier theorising with its sensory basis, demonstrating that Tenney's conceptualism, like that of La Monte Young, possesses a significant degree of 'perceptualism'.

4.9 Conclusion

4.9.1 Young and Tenney Compared

On first examination, the pairing of Young and Tenney is more of a narrative construct than the previous pairing of Partch and Johnston, as they are not in any way related as collaborators. However, Young and Tenney nonetheless share a similar conceptual background in much the manner that Partch and Johnston did: both approached composition from a perceptual–conceptual basis refined through experimental practices. Indeed, both composers enjoyed formative experiences in the same early New York Downtown milieu, with a particularly close second–degree connection via Fluxus: for Tenney's connction, see Higgins (2002, p.57). The Fluxus connection and perspective, even though short–lived and equivocal in both cases nonetheless reinforced their interest in perceptual matters. Most fundamentally (and directly), both also shared an engagement with the burgeoning research field of psychoacoustics, as evidenced by Young (1969) and Tenney's even more direct engagement through his Bell Labs post. As a result, their conceptualisation of microtonal materials was informed by an engement with the implications of perceptual processes.

Although Young favoured formalist, somewhat Pythagorean–derived models at one level of examination, the very complexity of these formal pitch relationships (such as the use of high prime–limit harmonics) is mediated by his attention to perceptual detail. Indeed, these intervallic complexities become frozen in a drone which will tend to reference each harmonic component back to its fundamental rather than encouraging a proliferation of new centres in harmonic space. Thus, Young's singular drones invariably conform best to a low–dimensional spatial model for this reason.

Tenney's microtonality, on the other hand, shifts between opposing structural tendencies: (1) the functional conception of harmonic space; and (2) a sensory–based model which is centred on the harmonic series as an integrating structure and which is more similar to Young's structural rationale. The drone–like spectralism of *Critical Band* (Tenney, 1988b/2001) and *Spectral CANON for CONLON Nancarrow* (Tenney, 1974) thus form a bridge between the theories and practices of the two composers.

4.9.2 Perceptually–informed Models of Microtonal Just Intonation

Microtonality based on just intonation found its early expression through the work of a cluster of twentieth–century American composers. The requirements of their new materials led to their adopting a variety of creative strategies, from instrument building to the development of microtonal performance practices for mainstream instruments and the use of amplified and electronic sources. In doing so, they developed a range of new musical models and codified aspects of their practice which were the result of the novel musical conditions created by microtonal materials. Although their rationales were somewhat distinct, a clear degree of commonality is present.

The use of graphical formal pitch–space models to group tuning ratios based on prime number factors in extended just intonation is a thread which is common to the work of Partch, Johnston and Tenney. This type of formal model was posited on assumptions that were fundamentally Pythagorean in origin: that consonance was related to the mathematical simplicity of interval ratios. However, all of these composers moved beyond this viewpoint to incorporate ideas from psychology and/or perceptual observations into their developing theories. Partch (1974) created an empirically–based graph of relative consonance/dissonance judgements, in addition to his formal representations. Johnston's psychologically–aware focus is exmplified by his proposal (Johnston, 1964) that the perception of pitch was essentially ratio–based, although this proved to be an inaccurate assessment in strict terms. However, he made a more lasting contribution to the modelling of microtonal structures though his multidimensional lattice spaces, which were modified by Tenney (1983) to include the cognitive–perceptual imposition of *tolerance limits* for the reduction of multidimensional proliferation.

However, Tenney's modelling of microtonal relationships also encompassed an even simpler ecologically–based approach in *Critical Band* (Tenney, 1988b), tempering his cognitively–based functionalism with a 'perceptualism' which reasserts the importance of sensory and ecological context. This aspect of sensory grounding perhaps has an antecedent in Partch's philosophical preferences (corporealism), but it finds its most direct parallel in the work of Young, whose careful specification of performance conditions and perceptual concerns results in a musical approach which is more extensively environmental/ecologically–based. Young's engagement with a range of extreme materials (high prime–based ratios) and performance conditions (long durations and significant amplification levels) results in a novel type of microtonal music which requires a delicate balance of presentational conditions and a singularly focussed engagement on the part of the listener for its full effect to be enjoyed. In the case of his installation work, such materials challenge a fundamental structural assumption of almost all other musical practice: that of music's identity as a time–based medium. In engaging with these environmental–style contexts, Young has developed an approach to pitch–space which is both holistic and muli–modal in the broadest sense. Rational tuning systems which are refracted through the lenses of amplification and long durations produce effects which are the result of delicate interplays between different performance/presentational modalities. The embodied exploration of a spatialised pitch–structure which is inherent in his drone–based installations is his most provocative contribution to the modelling of pitch–space. However, in more general terms, it is Young's strong affirmation of the importance of perceptual conditions in his practice which is his most transferable innovation and it is this perspective which he shares most strongly with James Tenney. In Young's installation work and in Tenney's *Critical Band* (Tenney, 1988b), the experience of microtonal materials in an ecological context (and, hence, as ecological–style structures) may contribute significantly to the process of perceiving microtonal music, providing a simpler solution to the problem of microtonal perception than that of complex (even if tolerance–limited) multidimensional lattice structures.

Even if such ecological attributes and models only contribute partially to a listener's engagement with microtonal materials, they have the potenial to address one of the frequent charges levelled agains microtonal practice: that the cognitive organisation of such a proliferation of intervals may limit listeners' ability to structurally engage with them; cf. Dowling and Harwood (1986, p.93) and McAdams (1989, p.184). If sensory attributes—or aspects related to the environmental/ecological context—of certain microtonal configurations reinforce or dictate cognitive structures related to these materials, they may provide a degree of support for microtonal systems which would otherwise be too complex for cognitive processing capacities to successfully encompass.

4.10 Chapter Summary

This chapter has paired La Monte Young and James Tenney, just intonation composers who have a shared perceptual–conceptual philosophy embedded within their experimentalist ethos (informed by the developing field of psychoacoustics) and situated through some similar formative experiences in the early NY Downtown scene; in particular through their connections with Fluxus. Their experimentalism has been discussed in relation to compositional practices which explored extreme conditions for some of their musical materials (such as long duration and dense microtonal sonorities) sometimes problematise a sole reliance multidimensional formal models. In addition, physiological/ecological structures of works such as *Critical Band* (Tenney, 1988b) and Young's sound installations are seen as providing examples of how ecological/embodied models/modes of engagement may contribute significantly to the perception of complex microtonal conditions, providing cognitive 'support' without increasing cognitive 'complexity'.

Chapter 5: The Psychology of Intervals: the Relationship Between Stimulus and Cognition for Microtonal Materials

This chapter is the first of two which will advance a framework for a theory of microtonal music which is perceptually and cognitively grounded. This theory will be informed by the musical practices and theories discussed in the foregoing chapters on the one hand and perspectives drawn from psychology on the other. The present chapter seeks to trace the relationship between microtonal stimuli and their potential reception (as perceptually and cognitively distinct materials) through an examination of the earlier stages of perception. In doing so, it will provide commentaries on contemporary theories relating to the encoding of pitch, together with an examination of issues relating to memory capacity and the nature of categorical perception for such materials.

5.1 Categories and Memory in Music Perception

A key issue in the development of a psychologically–informed theory of microtonal music is the manner in which complex stimuli are *parsed* into simpler forms for memory storage and retrieval. The structure of perceptual experience is obviously related to any constraints which are inherent in the nervous system and cognitive system's encoding and modelling of the percept in question. Snyder (2001) places this perspective at the centre of an account which seeks to develop a 'less Eurocentric' (Snyder, 2001, p.xiii) generalised music theory based on findings drawn from cognitive psychology.[148] In a broader context, Harnad (1987, p.1) discusses general principles of structured perception from the perspective of *categorisation*, noting that '[o]ne of the most basic questions of cognitive science is "How do organisms sort the objects of the world into categories?"' As such, the nature of an organism's transduction and cogntive processing of complex stimuli into discrete categories (*discretisation*) can be placed at the centre of the problem of perception for both generalised environments and musical presentations. In advancing his generalised music theory, Snyder highlights the importance of memory capacity and structure as influencing this process of discretisation:

> The organization of memory and the limits of our ability to remember have a profound effect on how we perceive patterns of events and boundaries in time. Memory influences how we decide when groups of events end and other groups of events begin, and how these events are related. It also allows us to comprehend time sequences of events in their totality, and to have expectations about what will happen next. Thus, in music that has communication as its goal, the structure of the music must take into consideration the structure of memory—even if we want to work against that structure.[149] (Snyder, 2001, p.3)

The cognitive constraints imposed by memory structures and processes and the manner of cognitive processing of sensory data therefore have profound implications for the construction of music and resulting musical experience. In particular, they pose challenges for the microtonalist in relation to the anticiptation of human capacities for dealing with the potential complexity of microtonal stimuli.

---

[148] Snyder's motivation in this is similar to that of the present project and of Tenney (1983), whose stated aim is the development of an 'aesthetically neutral' and less prescriptive theory of musical organisation which does not resort to normative restrictions distilled from common practice music.

[149] Two prominent discussions relating to this issue are McAdams (1989) and Lerdahl (1992)—these will be discussed in more detail below.

5.2 Memory in Relation to Music: Roles, Structures, Capacities and Strategies

5.2.1 Structures and Roles of Human Memory

Human memory has been modelled by cognitive science researchers as a number of distinct processes which carry out inter–related tasks as part of their general role of aiding humans in responding to a dynamic environment based on identifying patterns in sensory transduction, parsing this data into discrete elements and recognising identical or similar cases with reference to experience. In everyday language, these distinct cases are conflated under the generalised rubric of 'memory', for which, as Baddeley (1997, p.3) notes 'the use of a single term might seem to suggest that memory is a unitary sytem, albeit a complicated one.' However, current functional analyses of memory processes tend to divide human memory up into a number of distinct processes, satisfying relatively distinct roles. Snyder (2001, p.3; 2009, pp.107–109) structures his memory–based theory of music cognition based on a tripartite division of (1) *echoic memory/early processing*, (2) *short–term memory*; and (3) *long–term memory*. Snyder here tentatively relates these different processes to different levels of musical organisation, from (1) the grouping of harmonically related materials into fused percepts, through (2) melodic/rhythmic organisation to (3) larger–scale formal organisation, thus providing us with a summary encapsulation of their potential roles in the cognitive organisation of music.[150] (Discussions in previous sections have already

---

[150] Snyder (2001, p.16) notes that whilst this tripartite division of memory systems is a simplification of recent memory theories, the treatment of music from the perspective of three relatively distinct memory states/processes is appropriate due to the different timescales which these states/functions are specialised

begun to address the outline of some of these general cases—namely (1) and (3)—for microtonal music.) As Jan (2011, p.1) notes, Snyder (2001; 2009) provides the most detailed recent commentary on the potential connection between recent psychological research findings on memory roles and capacities and musical organisation. The present account will therefore proceed based on the structure of Snyder's model of music–related memory processes, outlining specific functional implications for microtonal music practice where applicable.

5.2.2 Echoic-memory/Early Processing

Echoic memory and early processing is the function of the human memory system for auditory data which stores uncategorised sensory data which has been the subject of trasnduction from the relevant sense organ into nerve impluses (Synder, 2001, p.4). Echoic memory could be conceived of as a short–duration and volatile[151] memory 'buffer' which contains this sensory data before it is the subject of perceptual and cognitive organisation.[152] A *feature extraction* process happens via specialised neural networks (Bharucha, 1999, pp.413–18) in which processes of categorisation and higher-order parametric structuring happen in relation to 'individual acoustical features' (Snyder, 2001, p.4). A further process of *perceptual binding* (Snyder, 2001, p.4) entails the grouping and segregation of these acoustical features into 'coherent auditory *events*' (Bregman, 1990, pp.213–394, cited in *ibid.*). The discretised structure has thus been the subject of basic, *bottom-up* (i.e. perceptual) organisation (*ibid.*, p.5) which is termed

---

to respond to. In doing so, he broadly follows the arguments of Pashler (1998, pp.319–356, cited in Snyder, 2001, p.16) in relation to the continued utility of the tripartite functional model of memory.

[151] Persisting for a second or two (Crowder, 1993, cited in Snyder, 2009, p.107).

[152] As Snyder (2009, p.107) notes, the function of echoic memory was first proposed by Crowder and Morton (1969, cited in *ibid.*) following research into *iconic memory* (Sperling, 1960, cited in *ibid.*), whereby a similar process happens for visual stimuli.

perceptual categorisation (Edelman, 1989, 1992, cited in *ibid.*, p.4; Barsalous, 1992, pp.22–24, cited in *ibid.*, p.82). Pastore (1987, p.38) provides a detailed formative theory of a psychophysical model of perceptual categorisation. This discretised representation is then stored in memory through an interaction between short–term and long–term memory (which will be discussed in more detail in the next section). These early stages of encoding and processing are described in figure 41, below:

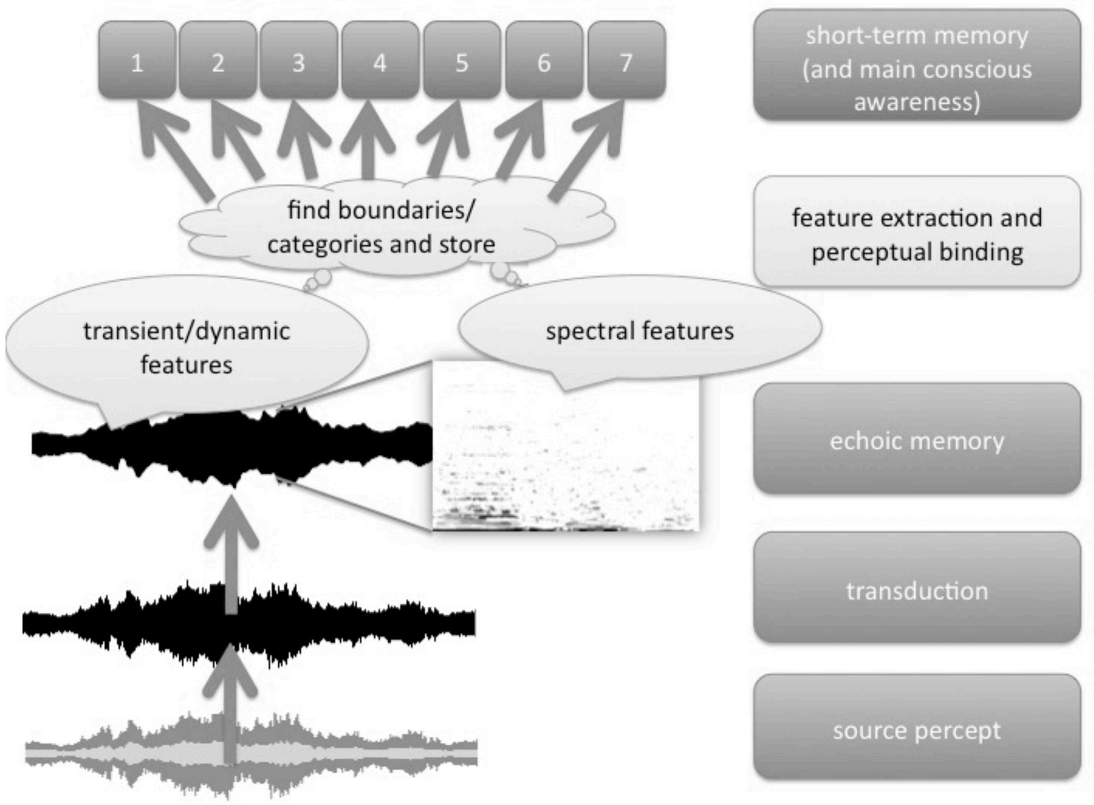


Figure 41: Processes of transduction and encoding/processing in echoic and short-term memory

After Snyder (2001, p.6), which provides a more complete account in relation to the interaction between these processes and long-term memory—see figure 42

In relation to microtonal music, echoic memory and early processing may be responsible for some aspects of the percetpual categorisation of pitch divisions, in addition to structuring perceptuable attributes such as sensory consonance and dissonance and timbre/sonority. The exact nature of this categorisation of pitch is obviously an extremely important one for the microtonal music practitioner, both in terms of the form of the structural divisions and to what extent such divisions are either innate features of the nervous system and bottom-up cognitive processes or are subject to alteration through learning.

5.2.3 Short–term and Long–term Memory Processes

The perceptual information from these earliest stages of perceptual memory then interacts with long–term memory (LTM) and short–term memory (STM). This interaction provides the opportunity for recall and recognition of categorised information. As Levitin (2002, p.295) notes, LTM is 'the kind of memory that most of us think of as memory', with features such as a durability/lack of volatility and the ability to retain a large amount of both conceptual and experiential/biographical information. LTM is thus employed for the long–term storage of categorised percepts, but also has a potential influence on the categorisation of perceptual experience through the activation of relevant stored memories, providing 'a context for current awareness' (Baars, 1988, pp.137–76, cited in Snyder, 2001, p.5), although most of its contents are not directly accessible to conscious thought unless so activated (Snyder, 2009, p.108). These activated memories are then available to conscious awareness through the medium of STM, which holds a comparatively small number of events or attributes, parsed according to perceptual or conceptual cognitive categories, in a volatile 'buffer' of approximately 4–8 seconds in duration (*ibid.*, p.107). STM is commonly hypothesised as a *working memory* for cognitive activity[153] (Atkinson and Shiffrin, 1968; Hunter, 1957; Newell, 1972; cited in Baddeley, 1997, p.50). The model of interaction between LTM and STM outlined above is known as the *modal model of memory* (Atkinson and Shiffrin, 1968, cited in Hunt and Ellis, 1999), whereby 'incoming information flows from the sensory register to short–term memory to permanent storage in long–term memory', with interaction between sensory memory and STM being dictated by processes of attention (Hunt and Ellis, 1999, p.113). The relationship between these processes is modelled in figure 42, below (next page). Based on this model, the cognition of musical structures (including microtonality) is mediated by the capacities and capabilities of two different memory processes.

[153] Baddeley (1997, p.50) notes that this hypothesis was first advanced prior to experimental evidence bearing it out, although later studies provided partial corroboration for this role and resultant performance degradation for cognitive tasks when STM was otherwise engaged (Baddeley, 1974, cited in *ibid.*).

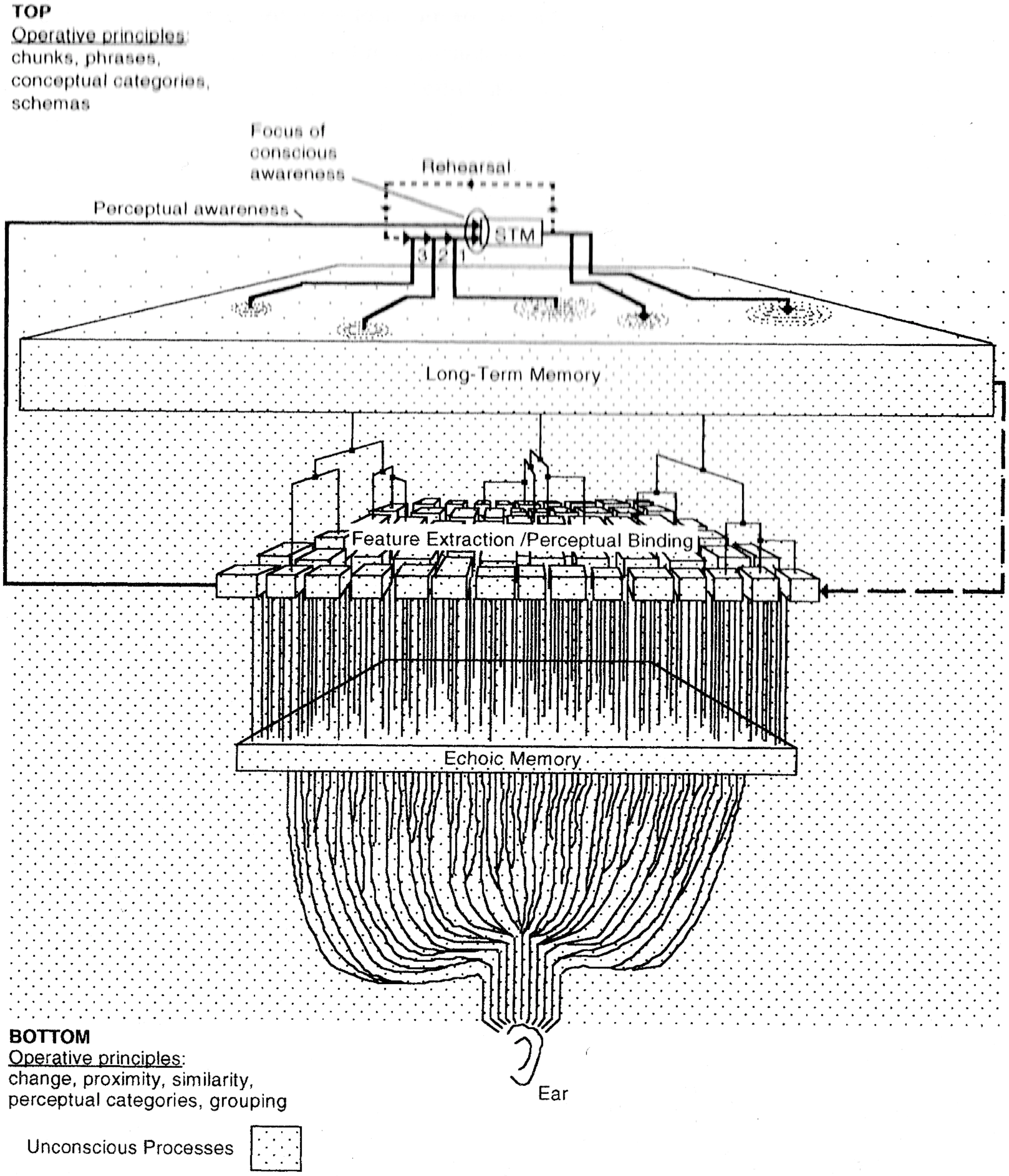


Figure 42: Modal model of relationship between echoic, long-term and short-term memory processes, from Snyder (2001, p.6)[154]

---

154 See discussion in Snyder (2001, pp.5–12) for further details.

5.2.4 Short-term Memory Capacity and Mnemonic Strategies

As the subject of a limited capacity in comparison with long–term memory, short–term memory will be focussed on here in relation to the modelling of potential cognitive limitations for microtonal musical cases. As discussed above, short–term memory has a very limited durational capacity, but this capacity may be variable based on the nature of the presented stimulus, in addition to a variety of processes of attention, rehearsal, grouping of data for ease of memorisation (known as coding/*chunking*) and strategies for information retrieval (Hunt and Ellis, 1999, pp.113–4). From this persepctive, the temporal limits noted above are in addition to a significant *element–capacity* limitation for STM—one influential early overview of work in the area (Miller, 1956) puts forward the view that capacity ranged from five to nine elements for particular cases of perceptual continua, hitting on the 'magical' number seven as a mean value between the two. If the ability to recognise and process pitch categories in music is solely defined by the capacity of STM in either model, then even significantly chromatic common practice music—let alone microtonality—provides a problematic case for music cognition if the orthodoxy related to this capacity is accepted.

However, this concept of a relatively fixed limit to memory capacity, whilst influential, is nonetheless the subject of some dispute within psychological research (Cowan, 2005, p.vii). Cowan's (2001, 2005) proposal is that STM capacity is more properly represented by *chunks* (nested groups of elements) rather than single discrete elements, whose typical number appears to be closer to four, but whose overall capacity may be higher due to this type of nested processing/grouping. Indeed, this grouping of discrete elements together to increase storage capacity in STM was originally proposed by

Miller[155] (1956, p.350), though the overall discussion is framed on the basis of the '7+/-2' limit (hereafter termed the *Miller limit*). The chunks (groups of elements) are organised in such a way that recall of some elements within an individual chunk is aided by one of the other elements (Baddeley, 1997, p.31). Strategies for remembering telephone numbers provide some insight into this process. For example, an example of a telephone number with full national and international codes is **0035317083733.** This is an eleven-digit string which would challenge the memory capabilities posited by Miller (1956). However, if parsed on the basis of international and national area codes, it becomes divided on the basis of the following:

00–(international prefix)–353–(international code for Ireland)–1–(national code for the Greater Dublin Area)–7083733–(number within this area).

Based on learned categories for some of these groups of numbers, some of this information is relatively redundant. For example, the international prefix is defined by an International Telecommunications standard (adopted by EU countries) as being 00 and can thus be remembered as a general case when travelling within the EU. The country code for Ireland is another learned category which is familiar to those who live there or frequently visit (or call) the country; similarly for the national code for Greater Dublin. Thus, the first two chunks provide data without requiring significant capacity for their individual numerals. Therefore the within–area number is the most significant 'user' of memory capacity. This may itself be broken into chunks based on grouping elements in a manner analagous to a year/month/date structure (or vice versa), such as **708–37–33** or **70–83–73–3** or **70–83–7–33**—the first and last may be somewhat easier

[155] Baddeley (1994) judges the central innovation of this article to be the concept and implication of chunking.

to remember, since there is an easier chunking facility available in '33' as 'double-3'. Thus, the number may be remembered as six separate chunks (three of which are easily subject to recall based on experience, and so are somewhat redundant in the immediate task of remembering a new telephone number for this country and region:

General international prefix–Irish international code–Dublin area code–708-37–'double 3'

The result is that the eleven-digit code is reduced to three frequently used categories (which are easily retried from LTM) and three or four other chunks. A similar example is provided by Levitin (2002, p.297), who provides an easily-parseable string of fifteen letters which reduce to five chunks based on spotting the connection and noting familiar acronyms:

FBICIAUSAATTIBM

Thus, chunking provides a method for the reduction of the number of discrete elements in STM, but requires the use of LTM to provide models for the identification of patterns/references or some form of mnemonic formulae.

5.2.5 Miller (1956) and Cognitively–based Theories of Music

Miller's (1956) limit has been influential in relation to cognitively–based theories of music, notably McAdams (1989)[156] and Lerdahl (1988). Miller's original account of limits for unidimensional stimuli contains explicit reference to musical stimuli. His discussion of previous research into capacity limits for pitch categories (Pollack 1952; 1953, cited in Miller, 1956, pp.344–5) notes a very limited capability for recognising

[156] Previously noted in chapter three in relation to Partch's practice.

such categories, with six divisions being the limiting case due to rapidly increased subject error beyond this point. (However, Miller himself notes in an aside (*ibid.*, p.344) the significantly better performance of 'musically sophisticated' subjects in discerning a wide variety of pitch categories, but does not proceed to explain it.) McAdams places the model of dimensionality at the centre of his discussion, treating musical parameters as distinct *form–bearing dimensions* (McAdams, 1989, p.181). This central concept is clearly related to Miller's discussion of *channel capacity* (Miller, 1956, p.344) which is described as the amount of data that a subject can provide about a given stimulus using absolute judgement, as in the experiments outlined in Pollack (1952; 1953, cited in *ibid.*).[157] McAdams advances a listener–centred model of musical structure which prefers perceptual and cognitive clarity provided by the careful use of form–bearing dimensions with a high channel capacity (McAdams, 1989, pp.181–2). In this regard, he singles out pitch and duration as providing 'strong dimensions', with several timbral dimensions being individually of weaker power and spatialisation and modulation rate dimensions being particularly 'weak'. Although pitch is cited as a dimension which is comparatively amenable to discrete structural parsing, it is nonetheless presumed to be limited to a relatively small number of divisions, based on the normative argument that most global pitch systems encompass divisions of between five and twelve elements, in contrast to the proliferation of intervals in microtonal systems such as Partch's 43-tone scale (*ibid.,* p.184).

Partch's approach is also criticsed in relation to discriminability, with McAdams noting

[157] Miller's paper is not mentioned explicitly until much later in the McAdams article (1989, p.193) but the influence of its early sections appears to pervade the overall thrust of McAdams's argument in relation to discrete treatment of channel capacities.

that the 43–tone division of the octave approaches discriminability limits for human pitch perception. However, McAdams uses ‘discrimination’ interchangeably between psychophysical perception and tonal cognition (which is more typically bracketed as *categorisation,* to distinguish form the finer-grained awareness in many perceptual discrimination demonstrations). In terms of perceptual discrimination abilities, Partch’s 43-tone scale does not challenge limits for sequential discrimination of pitch differences. Partch (1974, p.133) provides a table of this scale with cent figures for each division and the smallest interval is 14.4 cents in size. This compares with the *just noticeable limit* (JND[158]) limit for sequential discrimination of pitch which is commonly approximated as 0.5% frequency difference of the stimuli or 1/12 of a semitone, which is 8.333 cents[159] (Zwicker et al., 1957, pp.556–7; Roederer, 2008, p.33). Thus, although discrimination limits are briefly invoked with respect to form-bearing capacity for given dimensions of a musical work, McAdams’s central argument against cases such as microtonal proliferation of pitch intervals relates primarily to cognitive capacities related to Miller’s ‘7+/- 2’ memory capacity limit (for single dimensions), in addition to categorisation strategies (which will be discussed further below). On the basis of this particular strand of McAdams’s argument, the cognitive experience of microtonal practice appears to be cast into a significant degree of doubt unless particularly efficient chunking mechanisms are employed.

In a similar vein, Lerdahl (1988) discusses ‘cognitive constraints’ in relation to the use

---

[158] Frequently abbreviated in lower case in the psychological literature (jnd). The abbreviation DL (difference linen) is also sometimes used.

[159] Obtained by (12√2)^(1/12), or 5.9463%, see Dowling and Harwood (1986, p.92), who provide an approximation of 5.9%. In relation to JND, McAdams (1989, p.184) prefers a more conservative figure of 1/6 of a semitone (16.666 cents), most likely based on Houtsma (1968, cited in Burns, 1999, p.228). Nonetheless, Partch’s scale exceeds this measure by a generally wide margin for all but two of its intervals.

of pitch in musical composition, taking particular issue with the complexivist structures generated by some serial approaches. His motivation in doing so explicilty references what are regarded as stylistic excesses in mid–twentieth–century musical modernism in relation to its construction of *artificial grammars* to replace those of a 'fragemented and self-conscious' musical culture, although he asserts that 'an artifical grammar unresponsive to musical listening is unacceptable' (Lerdahl, 1988, p236). His is issue with some such grammars (namely serialism) is that they are 'cognitively opaque' (*ibid.*, p.231). It is notable here that Lerdahl is interested in reasserting a *listening grammar* as a defining central part of the compositional process, inspired by research, through what he terms (*ibid*., p.236) the more general 'rise of cognitive psychology', but also by cultural factors in what he terms the 'decline of the avant-garde'. In his search for a cognitively-informed theory of music composition, Lerdahl's particular target is complexivist serial music such as the work of Pierre Boulez (*ibid.*, pp.234–242), so only some of his discussion has a direct bearing on the matter at hand. Nonetheless, his primary argument—that it is easy to fall into the 'trap' of creating materials which exceed cognitive processing capacities when devising compositional systems—bears a strong resemblance to that of McAdams. Even more pertinently, he briefly invokes (*ibid*., p.250) the particular capacity restrictions in Miller (1956), but quickly provides a solution in the creation of a hierarchical (thus, multidimensional) structure to aid in chunking via primarily diatonic structures. In this regard, his restriction in the suggested number of divisions for clear transmission of musical structure is less proscripitive than that of McAdams: alternative and microtonal divisions of the octave are mentioned without explicit refutation, including Yasser (*ibid.*, p.246), South Indian musics and novel computer–generated sound materials (*ibid.,* p.251). Thus, Lerdahl places his primary faith in the careful configuration of materials to accentuate clear hierarchical structures rather than in absolute capacity–based restrictions on the materials themselves. McAdams does note the possibilities entailed in hierarchical structures abstracted from structures discernible within stimuli (McAdams, 1989, pp.184, 186–193, 195) but nonetheless prefers the cognitive economy provided by a relatively small number of pitch divisions and does not admit the more open–ended range of possibilities which Lerdahl does.

5.2.6 Variability in Chunking Capacities

However, as discussed above, the capacity of STM appears to be quite variable based on context (i.e. with regard to the perceptual modality and its presentational circumstances). As Cowan, Morey and Chen put it:

> It appears that immediate memory should be measured not in bits, but in units that are psychologically meaningful […] In this regard, human memory seems to operate in a manner quite different from computer memory, which is composed of many locations that can be turned on or off, worth 1 bit of information.
>
> (Cowan, Morey and Chen, 2007, p.48)

This is in contrast to the information–theory–derived focus of Miller: (Miller, 1960, pp.343–346, cited in Baddeley, 1994, p.353). The difference in capacities may be based on recognition of hierarchical structures and/or groups of elements from LTM (as in the chunking examples above[160]), thus improving chunking performance, or in the modalities of the information memorisation/rehearsal method. For our present purposes, it might be hoped that musical cues might be particularly suited to significantly better–

[160] See also Baddeley (1997, p.31) for discussion of early research findings in relation to memory capacity for words in meaningful sentences.

than–average chunking performance. In terms of examples from other fields of such modally–based effects on memory capacity, Ellis and Hennelly (1980, cited in Baddeley, 1997, p.56) found a discrepancy for memorisation performance for numbers between English and Welsh for bilingual speakers, with poorer performance based on subvocal rehearsal when using Welsh (which has longer vowel sounds than English). Based on the two types of examples discussed above, we appear to have (at least) two somewhat distinct cases for STM–capacity variation: (1) prior learning of structural categories and inter-category relationships for reduction of discrete elements required for storage and (2) method of rehearsal of elements. The role of prior learning is, as noted above, related to the creation of categories based on experience, including perceptual experience. This implies that some configurations of sensory percepts may be more amenable than others to memorisation within STM limits, even if the number of distinct elements to be organised in any dimension exceeds the 7+/-2 (or smaller) capacity. We also have an effect for different types of rehearsal of elements. Following on from Ellis and Hennelly (1980), Hoosain and Salili (1988, cited in *ibid.*, pp.56–7) found improved STM capacity for numerals for Chinese (Cantonese) speakers in Hong Kong who have a rapid articulation rate for numbers (with mean memorising capacities of 9.9 numerals), in comparison with Ellis and Hennelly's values of 5.8 (Welsh) and 6.6 (English). The rapid articulation rate is important because it appears to be related to specialised modular structures in STM which is divided on the basis of sensory modality, including a *phonological loop* for the processing of auditory information (Baddelely and Hitch, 1974, pp.80–81; Baddeley, 2003, pp.830–833). In this model, the phonologial loop is a volatile memory process (with a span of a few seconds before decay) which can be reactivated through rehearsal/re–articulation (Baddeley, 2003, p.830). This explains the variation in performance of STM for words describing similar concepts in different languages: shorter articulation time means that the reactivation can happen more quickly, storing more elements in the period of time before decay of the memories in question.

This may have a bearing on the performance of musicians[161] for musics which have a significant number of pitch divisions, including microtonal and significantly chromatic or dodecaphonic musical structures. With a sub–vocal sounding of heard pitches to be memorised, a fairly rapid degree of articulation could be managed due to the monosyllabic nature of the rehearsal. It is perhaps conceiveable that possessors of *absolute pitch* (AP), who can accurately encode and reproduce the tuning of learned intervals and melodic structures without recourse to external references, may utilise this type of rehearsal as part of their recall process. (In contrast, possessors of relative pitch (RP), which is more typical, may attain accurate performance with respect to size of intervallic sequence steps, but do not possess AP abilities in relation to absolute (i.e. unreferenced to external source) tuning accuracy (Burns, 1999, p.219).) Indeed, Ward (1954, cited in Ward, 1999, p.279) describes how one AP possessor significantly exceeded the ‘7+/- 2’ limit in performance, identifying 70 to 75 pitches without error (although this improvement in categorisation performance is not directly relevant to microtonality interval sizes, as opposed to general cognitive capacity for a large number of pitch categories). This is also an exceptional performance on the part of one AP possesor and such individuals appear to comprise only a small subset of Western populations; perhaps 1 in 10,000 in terms of standard definitions of AP (Levitin, 2002, p.303), so this particular effect, whatever its origin, does not provide a generally

[161] And, indeed, expert listeners who have a significant degree of musical training.

applicable modality for the sort of performance improvement on the Miller limit which would be required to ecnompass a microtonal system. However, Burns and Campbell (1994, cited in Ward, 1999, p.279; Burns, 1999, p.223) compared AP possessors with non–AP possessors for interval identification and discrimination within a single octave, resulting in non–AP subjects having reliable detection of the standard twelve divisions of the octave (and some microtonal abilities which will be discussed below) and AP subjects the previous corroborating findings of Ward (1954). Thus, both sets of subjects demonstrate reliable categorical identification which significantly exceed the Miller limit.

On the basis of an investigation into AP–style recognition/discrimination/production effects, Levitin (2002, p.304) also describes findings for AP–style reproduction of pitch standards for untrained listeners who have first been exposed to these standards via tuning forks and via pitch standards in melodies from CD recordings which they are very familiar with (Levitin, 1994, cited in Levitin, 2002, pp.304–306). This resulted in an effect which is similar to the classical case of AP described above, with *labelling* learned for the tuning of relevant tones. Although this labelling mode for potential rehearsal of pitch may be more long–winded than that found in classical AP (as it may be based on recalling the song in question, followed by a particular melodic fragment through its lyrics or some other mnemonic), it may account for one possible explanation for a potential increase in STM/working memory capacity for the particular phenomenon of musical pitch categories for both musically trained and untrained subjects. However, although this rehearsal-based concept provides a potential modality for expansion of memory capacity for pitch materials, it represents a particular type of active listening model and does not provide the significant increase in capacity which an efficient chunking approach could. As such, this account will now proceed to further investigate the strategies/modalities behind chunking processes as the potentially more generally applicable model for an increase in STM capacity.

Assuming that there is a possible circumvention of Miller's limit based on chunking may relate to the definition of some sort of organisational hierarchy for pitch categories. Miller's identification of the circa seven–item limit for short–term memory was based on the assumption that the stimuli in question are unidimensional and Miller himself found this capacity to be surprisingly low (Miller, 1956, p.344), given 'real–world' discrimination capabilities such as facial recognition.[162] In terms of typical musical experience, Dowling and Harwood (1986, p.107) note that the cognitive structure of pitch is more likely to be multidimensional rather than the simple unidimensional continuum assumed by the ANSI (1960) definition of pitch, accounting for the discrimination of a number of pitch categories which exceeds the Miller limit. Such multidimensionality may aid in the storage of a greater number of pitch categories through grouping into chunks encompassing a number of individual pitches. Miller (1956, p.347) himself notes that multidimensional cases improve the number of disitinct cases, interpreting the findings of Pollack and Ficks (1954, pp.155–8, cited in *ibid.*), who carried out early research into multidimensional auditory displays that accurately transmitted 150 distinct categories, which Miller considers to tally with what might be expected from capacities in 'ordinary experience'. In more recent commentary, Burns (1999, pp.220–224) notes that the performance of musically trained subjects (including those with both absolute pitch and more typical relative pitch abilities) exceeds the

[162] This led Miller to later investigate a wider range of capabilities through multidimensional phenomena (Baddeley, 1994, p.353).

Miller limit, with accurate category identification performance demonstrated for 12TET chromatic divisions, in addition to significant capabilities in identifying intervals whose tuning deviates from standard by around 30 cents or more (in sequential context). However, quartertone divisions (Burns and Campbell, 1994, cited in Burns, 1999, p.221) were not readily identified 'out–of–context' (i.e. as 'primary' categories rather than being identified as tuning deviations in sequential presentation).[163]

Nonetheless, based on the foregoing, it appears that musical pitch is a significant exception to the Miller limit (Burns, 1999, pp.223–4), providing the possibility of a partial endorsement for scale category structures with more than seven or so intervals (including significant capabilities with respect to identification of tuning deviations), especially given the musically decontextualised focus on sequential presentation of pure tones in the studies cited by Miller (1956).[164] One plausible explanation for this uniqueness of musical pitch with respect to other unidimensional stimuli is that it is not necessarily unidimensional in more typical/representative musical cases (this suggestion from Dowling and Harwood has already been noted above). Whether this putative multidimensionality might be an attribute of the stimulus itself or a structural context will be explored in successive sections.

---

[163] However, tempered quartertones may not produce resultant sonorities which are as distinctive on the basis of periodicity as just–intonation–based microtones.

[164] Burns (1994, p.218) does not specifically endorse microtonal practice (in terms of scale-category divisions) in this discussion of cognitive capacities; in fact, he casts doubt on how categorical microtonality is in traditions such as Arab and Indian musics, which deploy microtonal variants of intervals but do not utilise microtonal intervals sequentially (this is what I understand by his assertion that 'no musical cultures exist wherein the smallest *usable* interval is smaller than the semitone' [italics mine]. Nonetheless, he presents the case of pitch exceeding the Miller limit, which suggests that a different, more contextually-based model, is needed to account for musical pitch (which might allow for structured experience of microtonality in certain configurations).

5.3 Categorical Perception, Cognition and Microtonality

5.3.1 Categorical Perception and the Cognition of Categories

How musical materials are rationalised as in perception and cognition as discrete categories is an important aspect of the music theories of Snyder (2001, pp.81–6), McAdams (1989, pp.183–6) and Lerdahl (1989, pp.244–251). Indeed, the treatment of categories is an important component of more general psychological theories. Harnad notes the more general ecological importance of categories:

> One of the most basic questions of cognitive science is: How do organisms sort the objects of the world into categories? The problem is very general, for an object can be any recurring class of experience, from a concrete entity such as a cat or a table to an abstract idea such as goodness or truth. And sorting can be any differential response to the object category, from detecting and instrumentally manipulating it to identifying and verbally describing it. Categorization hence plays a critical role in perception, thinking and language and is probably a significant factor in motor performance too. (Harnad, 1987, p.1)

A categorical model for sensory perception is known as *categorical perception* (CP) and was first investigated in relation to the perception of speech phonemes (Liberman et al., 1957, cited in Goldstone and Hendrickson, 2009, p.2) Colour perception (with regard to the perception of continously–varying spectra as discrete bands) as offers another example of CP; see discussion in Goldstone and Hendrickson (2009, pp.1,5–6). A helpfully intuitive model of the CP process is provided by Harnad (1987, p.4); that of the *analogue–to–digital converter* (ADC). As such, categorical perception can be thought of as a perceptual or cognitive quantisation of a continuous variation of a particular sensory modality.

5.3.2 Musical Scales and Categorical Perception

A number of crucial questions for microtonal composition are related to this model of perception. Firstly, does musical pitch exhibit something similar to this type of discretised cateogrical perception on the basis of its cognitive-perceptual structuring (rather than on factors relating simply to the structure of musical instruments)? If so, to what extent are such categories relatively invariant based on particular frequency–range prototype conditions, or are they subject to being influenced by cultural factors (or, indeed, are cultural factors completely dominant in the perception of categories)? In relation to the general importance of discrete scale structures in music, McAdams invokes the parametric use of discrete categories for pitch, duration, dynamics and timbre for a majortiy of world musics (McAdams, 1989, pp.183–4), noting their imporance for cognitive economy in providing 'maximum information with the least cognitive effort' (Rosch, 1978, p.28, quoted in McAdams, 1989, p.184). McAdams here (pp.184–5) emphasises a learned (i.e. culturally mediated) model of category definition and relationships for musical materials, (although as noted above, he suggests that there is generalised cognitive capacity limitation related to STM). Everyday musical experience appears to suggest some form of categorical quantisation is indeed present and, as noted by McAdams, discrete structural divisions are embedded in a wide variety of muscial practices. As Burns (1999, p.217) notes, various ethnomusicological studies have shown that the division of pitch-space into discrete steps (even with performance nuance deviations from these steps) is 'essentially universal'. These broad category divisions appear to persist even when sound sources which permit continuous variation––such as vocals or unfretted instruments—are used exclusively (Stainsby and Cross, 2009, p.54).

With these aspects in mind, the discretisation of musical pitch appears to be embedded in a variety of musical approaches to a significant extent which overrides even those production/performance modalities which lend themselves to continuous variation. However, in terms of the question of whether this discretisation of musical pitch is a clear case of CP, there is sometimes some reticence and ambiguity in the musical literature with regard to commiting to the term. For example, Stainsby and Cross (*ibid.*, p.55) state that:

> It can readily be seen why a categorical mode of perception is necessary in speech communication, to accommodate the whole range of acoustically diverse sounds that come from different speakers of differing age, sex and accent. It is plausible that similar forces have shaped the selection of dominant scales in musical practice. […However…] there is also a mass of cultural and sociological factors which weigh on any purely perceptually driven evaluation of musical [scales].

Thus, the potential presence of CP effects in musical pitch materials is seen here as being related to the ecological demands of categorisation in other auditory modes, with the caution in applying the term in this case coming from the degree of possible variability due to cultural factors which might entail a weaker or more mutable form of categorical parsing for pitch. Nonetheless, Burns cites research by Siegel and Siegel (1977, cited in Burns, 1999, p.221) which demonstrates that clear CP effects (similar to those found in speech stimuli) have been found for musicans' magnitude estimations of interval sizes: magnitude estimation was quantised on the basis of much larger frequency intervals than the stimulus itself varied by, with abrupt transitions from one to another, which suggests CP. On the basis of a broad survey of experimental research, Burns concludes (*ibid.*, p.229) that CP effects are generally confined to 'musicians' (defined as presence of musical training, so it could include non-practicing musicians, perhaps better termed 'expert listeners'). Thus, CP, if it is a significant factor in micrtonal perception, may be a factor which is limited to more expert listeners. That said, the experiment by Levitin noted above (Levitin, 2002, p.304) suggests that improved performance with regard to accurate pitch and interval recognition may be possible with moderate exposure/training.

More generally, for the microtonalist a crucial existential question relates to whether particular psychophysical cases or cognitive limitations inherent within categorisation processes may reduce the capacity for perceiving smaller pitch intervals as discernible categories (i.e. whether the discretisation process, where present, tends to produce categories larger than common microtonal intervals). This issue will be explored in the next section in the context of factors which might contribute to CP for musical pitch and how it might be organised.

5.3.3 Musical Pitch Categories: Sensory, Cognitive–Cultural or Both?

The early definition of CP held that its quantisation/recoding is absolute and that within-category distinctions effectively 'do not exist' (Pastore, 1987, pp.30–32), such as is the case for the perception of phonemes (Liberman et al., 1957, cited in Goldstone and

Hendrickson, 2009). In this classical case, the quantisation/recoding is considerd to be absolute; as Pastore (1987, pp.30–32), 'distinctions within a set of perceptual responses do not exist'. However, this version of the effect clearly does not account for typical musical experience of pitch categories, as within-category distinctions in terms of tuning are still salient in many circumstances. Pastore (1987, p.32) notes this issue of partial versus absolute quantisation/recoding is significant in the search for a more broadly–applicable definition of CP which would encompass improved performance between categories whilst retaining discrimination abilities. An alternative CP model (which aimed to account for a greater range of categorisation phenomena) was proposed by Studdert–Kennedy et al. (1970, cited in Pastore, 1987, p.32), which combined 'distinct labelling categories with sharp boundaries' along with some possibility of 'less than absolutely discrete perception' for certain stimuli *within* categorical regions. This second model of CP therefore accounts for cases where listeners are better able to discriminate between within-category stimuli than strong CP would account for and, as Goldstone and Hendrickson (2009, p.4) put it, supplement 'categorical codes with a richer, *perceptual*, less digitized encoding' [italics mine]. In the musical context, it might be summarised as comprising both schematic stepwise structures along with residues of the sensory detail which articulates thes structures. This model of CP more successfully accounts for musical cases where a listener might recognise a particular category of note in broad *pitch-class* terms, but might nonetheless recognise microtonal variations/distinctions within this pitch–class 'region' in another aspect of their cognition, perhaps in terms of expressive nuance, see figure 43, following page, after Snyder (2001, p.87).

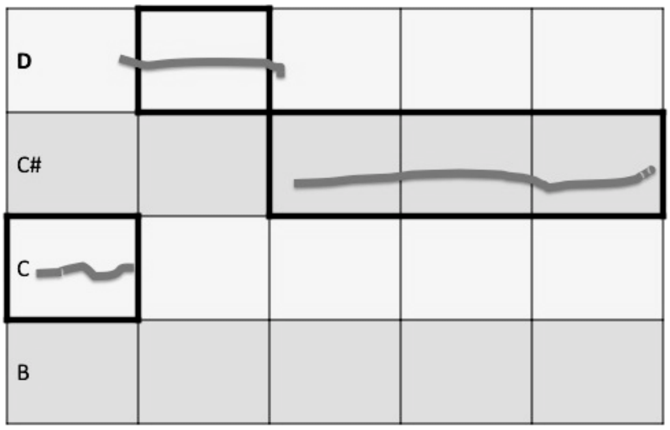


Figure 43: Model of pitch categorisation and temporal quantisation in Western 12TET music in comparison with frequency variation (nuance) within stimulus, after Snyder (2001, p.87)

This model also appears to tally with Clarke's (1987, p.224–228) suggestion of a distinction between structure (based on discrete categories) and nuance, which carries expression. Clarke's suggestion of such a division is primarily based on temporal aspects[165], but McAdams (1989, p.184) invokes this idea in relation to pitch divisions and Snyder (2001, pp.86–7) employs it in the context of a general description of musical categorical discretisation versus nuance.[166] However, this model also raises questions regarding the role of culture in defining these categories (and the more general corollary of how fixed or variable these category definitions might be, as the

---

[165] Although he does propose a more general case (nonetheless framed in terms of temporal division) whereby form is defined at the level of abstract properties as opposed to sensory characteristics (Clarke, 1987, p.230).

[166] Indeed, it is embedded in popular music production practice through 'quantisation-plus-residue' structure implicit in the software interface of tuning correction/quantisation tools such as Antares Auto-tune (Antares, 1997) and Melodyne (Celemony, 2001), in addition to the earlier modalities of the MIDI protocol, which describes pitch-space in quantised semitone-based fashion but allows for the addition/superimposition of 'expression' through *pitch-bend* controls.

categorical quantisation/recoding appears to permit significant degrees of discrimination of difference within categories which might form the basis for category boundaries to change with context. Moreover, in the case of a strictly unidimensional percept (which musical pitch is often conceptualised as), the question of where divisions might be drawn could conceivably be broadly culturally relative and essentially arbitrary, based on exposure and learning within a given musical culture. As such, the discrimination of differences within categories for unidimensional stimuli appears to offer the possibility of a significant degree of cultural relativism in category definition.

The issue of cultural relativism in perception has been the subject of considerable debate in the psychology literature, with language-dependent influence on CP effects in colour being an area of particular focus; see Hendrickson and Goldstone (2009, pp.5–6) for a survey of this issue. This language–dependent effect was first proposed as the *Whorf hypothesis*[167] (Whorf, 1956)*,* also termed *linguistic relativity* (i.e. language–specific relativity), relating to categorisation of sensory percepts. This theory implies that perceptual experience is to some degree culturally–specific via linguistic definition of category boundaries. On the other hand, a *universalist* hypothesis would relate category definition to psychophysical factors: salient aspects of various conditions of sensory phenomena as mediated through an organism's perceptual physiology and lower–level cognitive systems. Since colour perception is based on a unidimensional stimulus variation, findings for it might provide some clue as to the behaviour of pitch in terms of potential roles for linguistic relativity or psychophysical/cognitive universals in CP.

[167] Also popularly termed the Sapir–Whorf hypothesis after Whorf's teacher, Sapir—see Kay and Kempton (1984).

Early cross-cultural research appeared to indicate that cultures with very different colour categories nonetheless demonstrated memory performance consistent with a universalist CP (Rosch et al., 1972, cited in Goldstone and Hendrickson, 2009, p.5). However, Roberson et al. (2005, p.403) found some evidence supporting relativism through an investigation of the Himba tribe in Northern Namibia, who exhibit different CP categories than those found in English: Himba speakers exhibited improved performance in memory–related tasks when colours presented inhabited different linguistic categories. Furthermore, a study of Russian and English speakers (Winawer et al., 2007, cited in Goldstone and Hendrickson, 2009, p.5) found similar results. However, Regier et al. (2010) note that a completely oppositional definition of this issue may be more likely to obscure than illuminate, provide a 'hedged universalist answer' to the issue:

> There are clear universal tendencies of color naming, but that linguistic convention may nonetheless play some role in determining category extension—a hedged universalist answer. (Regier et al., 2010, p.2)

The particular universal tendencies which are relevant for colour are not specifically relevant to our discussion of pitch categorisation and will not be discussed in detail here. However, what is of striking potential relevance for investigations into musical pitch division is the finding that the linguistically (hence, culturally) relative effects in the experiments noted above could derive from the elaboration of conceptual category definitions on top of lower-level perceptual encoding, an interpretation which has been borne out by neuropsychological research into CP for prelinguistic infants compared with adults (Goldstone and Hendrickson, 2009, p.5).[168] As can be seen from perspectives above, the assessment of colour perception appears to be balanced between universal and linguistically relative effects, the latter of which appear to operate as modifications of existing category boundaries. In addition, some of the findings noted above suggest that these modifications may provide profound alterations of perceptual experience in relation to applying these category modifications at the perceptual rather than interpretative level. The findings in relation to colour thus leave the door open to findings in other domains which might be balanced between universals and lingustic/cultural relativistic effects on their category definitions.

However, the broad structure of musical scales in a variety of musical cultures appears to exhibit a significant degree of potential universality through the relative similarities of their scale structures. In addition to the phenomenon of octave equivalence (discussed above), the overall structure of musical category divisions (such as those in Western, Chinese, Indian and Middle Eastern scales) tends towards universality, with the structure of scales in the musics noted above bearing strong similarities to each other and to intervals found within the harmonic series (Burns, 1999, p.248).[169] Stainsby and Cross trace this connection to the pheonmena of sensory consonance and dissonance (Plomp and Levelt, 1965, cited in Stainsby and Cross, 2009, p.55) and thus base the possible psychophysical contribution to scale division on cases of simultaneous

---

[168] Indeed, there is also some suggestion that these linguistic (and, hence, conceptual) category definitions might provide more than a linguistic mediation of lower–level perceptual boundaries, but might actually redefine them (Notman et al., 2005, cited in Goldstone and Hendrickson, 2009, p.6).

[169] See also discussion in Sloboda (1985, pp.240–242) in relation to a survey of similarities and differences in a range of musical cultures which goes beyond those above to include African cultures, which contains brief mentions of scale structures.

presentation of intervals.[170] This suggests the somewhat Pythagorean possibility that a prototypical inspiration for such divisions is to be found in the structure of harmonic stimuli, hence this might be a candidate for a musical 'universal' (in the sense of a broadly dispersed tendency which describes a majority of cases). However, Burns (1999, pp.248–9) also notes that a wide variety of ethnomusicological studies have shown that this is not universal in cultures which primarily utilise tuned percussion instruments, although he estimates that the majority of cultures utilise materials influenced by harmonically–based timbres and consonances. Thus, whilst scale configuration appears to be a predominantly culturally–relative phenomenon in *some* cases, it may be subject to to influence from particularly salient psychophysical phenomena so that certain broadly dispersed cross-cultural similarities may be discernible in scale structures. The most common similarity is *octave equivalence*—see survey by Burns (*ibid.*, pp.252–5). This treatment of pitches which are separated by octaves as cognitively equivalent appears to be a candidate for a universal (or near-universal) in human musical practice (Shepard, 1964), leading to the majority of human scale structures being based on the division of this interval.

A further contributing factor to the universal tendencies in musical structure may be found in formal/structural aspects of the scales themselves—namely diatonicity based on unequal step size— which may aid in processes of memorisation and retrieval

---

[170] Although this does not easily account for the development of such tuning divisions in monophonic musical presentations (Burns, 1999, p.242), such as those found in Ancient Greek music. However, given that the musical cultures cited above each have a significant body of music theory, it may be that their convergence around broadly similar scale structures relates to the influence of similar Pythagorean-style discoveries of connections between low-number integer ratios and consonances through a process of experimentation with various tunings in comparison with others, even if the mode of performance was primarily monophonic in some cases. Indeed, Burns (p.257) later concedes that quartertone music may be feasible 'given sufficient exposure', whilst still preferring twelve divisions as a general limit.

through the hierarchical implications which this engenders (McAdams, pp.187–190; Lerdahl, 1989, pp.250–1; Sloboda, 1985, pp.254–257). Indeed, beyond offering a potential explanation for strong category-related performance for pitch in terms of chunking, diatonicism has been considered as providing a generative basis for human scale structures. In this regard, Balzano (1980, p.83; Balzano, 1982, pp.347–349) describes how diatonic structures which are easily available from the 12TET supraset provides an alternative explanation for the convergence of scale structures in similar forms (Balzano, 1982, cited in Burns, 1999, p.252). In summary, this theory examines formal properties of the octave into twelve equal segments, which correspond to a cycle of pitch classes, with coexisting diatonic and chromatic patterns embedded in relatively simple potential formal/functional relationships of this particular octave division and similar structures within a generalised class of equal temperaments[171] (Balzano, 1980, pp.73–74). The theory as summarised by Balzano (p.83) offers an explanation of scale division primarily on the basis of parsimoniuous formal relationships, allowing for the co–existence of stepwise/melodic, harmonic/modal definitions (thirds) and key relationships in simple formal/procedural relationships, with the diatonic scale which is a subset of such an equal temperament balancing melodic and key–based aspects of formal structure with relative formal simplicity.

However, from a more ecologically/perceptually–based perspective, it could be argued that Balzano's formalist representation *describes an emergent formal elaboration* upon materials which are more likely to have been initially selected based on

[171] Balzano also notes that cases of equal temperament which possess these features can be described by $n=k(k+1)$, where n is the number of equal divisions of the octave and k is any positive integer, thus the next-lowest equal temperament which facilitates this balance is 20TET, followed by 30TET. A more general discussion of formal models of pitch-space and their potential relationship to cognitive capacities will be provided in the following section.

perceptual/sensory attributes (i.e. it elucidates the salient structural axes within the more fromally-based model of tonality which developed in Europe). In contrast to this position, a sensory–based explanation could offer a potential explanation for the broad range of world musics which are based on the deployment of intervals which are close to small-number integer ratios (primarily presented using sources which are themselves based on harmonic spectra). Some form of explanation is required for the broadly dispersed convergence of scale features; as Burns and Ward (1982, p.262) note, given this convergence of practices amongst geographically disparete cultures, a completely culturally relative genesis of scale construction appears to be exteremely unlikely. Therefore, if Balzano's non–perceptual formalism is not favoured, explanations which are somehow related to features in harmonic spectra appear to provide the most plausible basis for this broad similarity in musical practices. The two prototypical theories which favour perceptual phenomena are those of Plomp and Levelt (1965, pp.549–551)—who support the position that musical scale categories are influenced by 'prototypes' which correspond to harmonic intervals due to sensory consonance (albeit with an overlay of culturally-relative pitch standards)—and Terhardt (1978, pp.488–9), who suggested that exposure to environmental stimuli such as human speech provides the materials for learned interval templates.

Terhardt's conception of harmony might be best described as a sort of *ecological formalism:* ecological, in the sense of being influenced by environmental stimuli, and formal, in the sense of being most influenced by structural features within stimuli rather than their sensory effect (in relation to sensory consonance); see also Burns (1999, pp.241–2), who notes that this template-based model of harmony as form is likely to be be altered through cognitive processes of approximation. Nonetheless, the concluding summary by Burns (1999, pp.250, 257) implicitly endorses the Plomp and Levelt position which is itself based on the approximation of harmonic intervals through culturally-specified scale structures elaborated on harmonic prototypes initially chosen due to a preference for maximum sensory consonance; Stainsby and Cross (2009, pp.51-3) also endorse the perspective of Plomp and Levelt. Thus, there appears to be a strong candidate effect within psychophysics for the prototypical definition of some musical categories and these prototypes appear to be broadly recognisable in actual musical scales.

The case for a universalist psychophysical influence on CP has been examined by Pastore (1987), who has interrogated the concept of psychological uniformity in percepts such as pitch which are considered to be unidimensional in many accounts. As noted, the Miller limit holds for unidimensional stimuli which are the subject of a uniform (or, at least, close to uniform) psychophysical equivalence. A corollary of the quantisation effect of CP entails that discrimination performance is significantly increased between categories over discrimination abilities within category boundaries (Harnad, 1987, pp.1–3): for certain stimuli, very small changes in magnitude can be much more salient at certain points on a continuum than at others.[172] Pursuing a psychophysical explantion for CP, Pastore (1987, p.38) references Stevens (1975, 1981) to the effect that the psychophysical transfer function for auditory perception may not be uniform across the source continuum. This nonuniformity may imply that there are nodes of increased psychological distance—Pastore here terms it *perceptual distance*—

---

[172] This is one of two competing perspectives on category definition, the other being the definition based on typical prototypes which occupy the centre of categories (Rosch, 1975, cited in Goldstone, 2010, p.6). The boundary–discrimination perspective will initially be favoured in the present account, due to its conceptual compatibility with models based on more basic bottom-up perceptual processes.

which are closer together in the source continuum than this psychological *distance factor* might imply. This generally univeralist/psychophysical basis for CP was also previously discussed by Berlin and Kay (1969, cited in Harnad, 1987, pp.13-14):

> The [...] universalist view is that category boundaries tend to occur where nature has put them, either because there are discontinuities in the world[173] or because our nervous system innately imposes discontinuities.

Whether the source of this putative effect is based primarily on aspects of environmental structures, sensory nervous system structures, or both, the result is that there will be the addition of an extra dimension in the modelling of a sensory phenomenon if the psychological distance is not uniform across the psychological transfer function. For example, such a case may happen if there is a secondary perceptual effect which is significant at certain points along a continuum, even if the transfer function results in a unidimensional equivalence for a given parameter of a source and psychological magnitude in its primary perceptual effect. As Burns (1999, p.213) notes, this type of situation contrasts with the more typical situation in psychophysics, where the Miller limit applies and discrimination between two stimuli is a simple (monotonic) function of separation.

As a corollary of this point, if there is a significant secondary effect which contributes to increased perceptual difference between two points, the capacity for the number of categories which can be processed through short-term memory is potentially increased beyond the capacity implied by the Miller limit, in addition to the contribution of

[173] And our nervous system has adapted in a particularly successful fashion to its environment, such that it provides cues which efficiently contribute to this perceptual delineation.

perceptual factors to the definition of categorical spans and positions. If such a situation were to apply to microtonal materials, the number of categories which could be encompassed could exceed this Miller limit sufficiently to allow for their treatment as cognitively distinct categories, although exactly where the interval boundaries were drawn would contribute signficiantly to this improved performance. Pastore's (1987) account focusses largely on audition, with discussions of phonemes in speech stimuli (which, as noted above, provide a particularly strong case of CP) and tonal stimuli. His argument, based on discrimination abilities for a particular continuum as enumerated by the *difference linen* (DL—alternative terminology for the JND) is that certain psychophysical conditions cause an increase in discrimination abilities at various points and that this information can provide results which are consistent with CP abilities (Pastore, 1987, pp.36–9, 48). As such, Pastore provides a model which is perceptually–based and which centers on *category boundary effects*, with discrimination abilities seen as directly connected to the assignment of percepts to particular categories.

In terms of this model's utility as a theory of CP for musical pitch, it benefits from not needing to assume completely discrete perceptual encoding based on some form of specialised feature detection[174] (Pastore, 1987, pp.29, 32, 36–7), which, as noted above, is consistent with CP findings for pitch. As Pastore notes in his conclusion:

> I would argue that examining the perceptual properties of a continuum in terms of the DL can provide far more information about the relationship between the physical continuum and the perception of that continuum than attempts to find "categorical perception" for that continuum. Taking my argument to an extreme,

[174] This is one explanation for the stronger CP effect found in categorisation of speech phonemes.

> CP, unless demonstrated to be absolute really only tells us that there is something special about the boundary stimulus [such that it delineates the start of separate perceptual categories]. (Pastore, 1987, p.48)

In relation to its potential applicability to microtonality, Pastore's model brings an ecological-style focus on the importance of peceptually distinct cases within the source stimulus, as opposed to explanations based on higher–level cognitive processing. For microtonality, this sensory-based definition of categories can be seen as relating to perceptual cases such as the attributes of sensory consonance and dissonance in simultaneous presentation of intervals. Therefore, a secondary attribute (sensory consonance/dissonance) of intervals which move relative to each other along a pitch continuum (i.e. the primary axis in question) becomes of primary importance in the structured perception/cognition of these interval sizes.[175]

In this regard, Partch's graph of comparative sensory consonance/dissoannce (as discussed in chapter three) and Plomp and Levelt's studies are particularly important models of microtonal experience due to the perceptually distinct cases at nodes corresponding to harmonic intervals. It is also generally consistent with the sensory-based xenharmonic scale construction outlined in Sethares (2004), although his choice of focussing on minima in the sensory dissonance curves tailored to the spectra of component sounds is based on trying to moderate sensory dissonance rather than directly trying to achieve multiple distinct cases of sensory consonance/dissonance magnitudes (even if significant differences may result as a by-product for some interval

[175] This explanation is also consistent in broader terms with one crucial stage/progression in Tenney's multi-stage theory of historical consonance/dissonance concepts (CDCs), that of the progression from CDC–2 (focus on sensory attribute) to CDC–3 (beginnings of functional definition of harmony).

cases). The ‘higher–order interactions’ (Pastore, 1987, cited in Harnad, 1987, p.9) may produce nodes of increased perceptual salience (i.e. perceptual discontinuities) for relatively small stimulus changes due to the presence of such interactions in more complex stimuli; this is a case which is clearly likely to occur in typical musical cases presenting combinations of tones which themselves contain numerous partials. Pastore also provides a case which is not due to psychophysical discontinuities, whereby the presence of a constant reference stimulus for a smoothly-varying continuum[176] will cause the DL/JND magnitude to decrease near this point due to facilitating comparisons with this reference which reduce uncertainty/noise in the perceptual system (Pastore et al., 1977, cited in Pastore, 1987, p.37).

While these proposed explanations for CP clearly don’t directly account for monophonic musical cases, they do benefit from providing explanations consistent with the preponderance of similar musical scale structures in a range of global cultures which bear some resemblance to harmonic intervals. Furthermore, it is possible to imagine a mechanism similar to Pastore’s reference-based model operating in monophonic cases, whereby a listener compares new tones to reference tones which are recalled/rehearsed in memory. In this regard, the experimental findings of Scharf et al. (1987) may be of relevance to Pastore’s perspecitve. This research (*ibid.*, p.222) found improved perceptual discrimination abilities for *sequential* pitch cases when successive stimuli occur within a set division of the critical bandwidth, suggesting that some form of perceptual priming takes place (and therefore positing a memory-based effect which could relate to Pastore’s concept of an effect for references in facilitating accurate

[176] Which obeys Weber’s law, i.e. which has a logarithmic relationship between stimulus and percept.

comparison with new stimuli). Scharf et al. (*ibid.,* p.215) compare this process of auditory expectation to other ecologically useful mechanisms of visual expectancy for spatial location (i.e. objects which are grouped relatively closely within a visual field are more likely to be prioritised in attention than objects outside this immediate range). In terms of their theory of perceptual attention bands, Scarf (*ibid.*, p.222) specify the optimum range for this effect as somewhat less than the critical bandwidth (approximately half the critical bandwidth). This range encompasses microtonal interval variations: as such, it is possible that this type of perceptual priming works in concert with Pastore's DL-based theory to focus attention on small pitch variations if the surrounding pitches are within this attention-band (as may be the case with microtonal music which utilises long durations). Indeed, Lerdahl (2001, p.81) makes a similar analysis in relation to its potential role in both general melodic coherence (through its encompassing step-wise grouping) and, more particularly, its potential to increase the salience of chromatic nuances. Lerdahl does not specifically mention microtonality, nor Pastore's theory, but since microtonal intervals are found within this band, such a mechanism can only act as a theoretical corroboration of their perceptual relevance in certain circumstances.

One potential problem with the invocation of higher–order interactions which is used by Pastore to explain CP is that such cases may be subject to variability with regard to different stimulus conditions. It might be expected that some aspects of stimulus conditions such as relative amplitude levels and timbre–related factors such as configuration of harmonic spectra might affect categorisation performance. As noted above, such a model is consistent with scale construction explanations found in Plomp and Levelt (1965) and Sethares (2004), but with particular regard to the latter, whilst

Sethares demonstrates means by which a wide range of spectrally–based scales might be constructed to minimise sensory dissonance; however, neither acccount directly addresses CP or capacity issues in cognitive processing. He demonstrates scale variability with regard to the generation of scales to match inharmonic timbres, such as his modified 12TET scale examples[177] with stretched 2.1 octaves and timbres with the same degree of spectral stretch (Sethares, 2004, sound examples 1 to 5). These examples appearing on casual listening[178] to be more consistent/less 'unfamiliar sounding' than those where either timbre or scale structure differ to a significant degree (*ibid*).

Thus, general scale structure/category division appears to be validated on the basis of salience of particular cases of interacting sonorities within the range of intervallic combinations which are related to their relative positions with respect to harmonic series intervals. As noted above, this does not necessarily directly explain choice of pitch category divisions for monophonic presentations if it is taken as a complete explanation for musical CP (and related scale structure definition). However, if a cognitive adjunct to this model matched broad interval divisions to the frequency references embodied within a generalised template for a harmonic timbre—as envisaged by Terhardt (1978)—then this type of model could explain preferences in both polyphonic/homophonic and monophonic presentation. If so, a question arises as to

[177] These examples are congruent with standard practice for 12TET in common practice Western music, whereby relatively brief instrumental articulations appear to ameliorate minor deviations from more precise rendering of harmonic intervals.
[178] These 'artificial scales' have not been the subject of significant investigation by psychologists in terms of widespread subject–testing; nonetheless, the effects are 'not subtle', as Sethares has put it (Sethares, 2004, p.3). However, the general principle is established through the practice of similar (by mode, if not by degree) processes of stretched tuning to compensate for inharmonicities in piano timbres, in addition to the scale structures of Javanese gamelan, which are tailored to the inharmonic timbres of a given set of metallophones (Sethares, 2004, pp.199–220).

whether such a model might be based on a learned single-instance (archetypal) harmonic series structure (as Terhardt suggests) or whether it cross-references within the source stimulus (which might be suggested by the relative strucutral familiarity of the Sethares stretched scales noted above).

If the latter case were applicable, aspects of timbre related to the structure of frequency spectra might be expected to affect performance in the recognition of pitched stimuli. In this regard, a finding by Ferrer–Flores (2007) suggests that this interaction between 'external' frequency structure (interval structure) and 'internal' frequency structure (frequency spectrum of the stimulus) might contribute to the recognition of intervals. The project investigated the potential effect of timbre choice in the context of ear training and found an effect for an interaction between timbre chosen and memorisation of microtonal intervals based on quartertones in melodic contexts[179] (Ferrer–Flores, 2007, p.34). This suggests that timbre chosen affects memorisation of melodic intervals for spans which are just beyond short-term memory (STM) spans (*ibid.*, pp.8,42–6, 57–8). Particular timbral attributes/component percepts which were surmised to be relevant to this effect included *spectral roll-off* (i.e. how 'quickly' spectral components become progressively lower in level as the harmonic series progresses upwards, similar to *slope* in an artificial filter's cutoff response), *spectral centroid* ('centre of mass' of the spectrum, correlated with perceptual 'brightness') and spectral spread—'variance of the frequency discribution'(*ibid.,* pp.54–5).[180] Lower values for each of these cues correlated with disimproved performance for accruate identification of intervals (*ibid.*,

[179] In this particular experimental context, this scale–division approach was chosen due to a search for less familiar interval divisions which are less strongly embedded in long–term memory so that the effect of timbre on a more active memorisation process could be studied (Ferrer–Flores, 2007, pp. 8,34).
[180] See discussion of these sensory/perceptual correlates in Grey and Gordon (1978).

p.56). Although this study was expressly designed to investigate effects outside short-term memory spans, it is conceivable that such effects could also affect interval recognition within such spans, therefore providing a potential connection with Pastore's model of CP as grounded in the structure of sensory phenomena. In addition, such a cross-referencing of structure from one aspect of a percept to another would be consistent with an ecological/multi-modal model of perception.

5.4 Conclusion: Memory, Category and Performance for Microtonal Intervals

This chapter has begun to trace a theory of how microtonal music may be consistent with current perceptual and/or cognitive models for the treatment of individual musical intervals. It has focussed on potential issues with regard to limited short–term memory capacity (which is one of the frequent bases for arguments against microtonal practices), in addition to providing a commentary on the potential form, role and origin of categorical perception for musical pitch. The nature of this type of perceptual quantisation is obviously of huge import for microtonal experience: any model of the potential contribution of microtonal materials to structured perceptual and cognitive experience (other than more momentary or subliminal expressive inflections) must be consistent with such processes.

In describing current theories of categorical perception/quantisation, this account has begun to question whether the delineation of pitch intervals in musical scales is related primarily to bottom–up sensory attributes or top–down cognitive interventions (or whether such cases occupy a bi–directional middle ground between the two). This question has great bearing on where we might look for a potential 'defence' of microtonality. Do we seek it in primarily bottom–up sensory processes based on discernible structures within the source stimulus as it interacts with the basic psychophysical perception systems of humans? Or do we look for it in top–down cognitive interventions, which imply that hierarchical structures may contribute to the efficient chunking of pitch materials in perceptual experience, thus circumventing the more limited capacity of short–term memory with regard to unidimensional stimuli.

The question of whether universal constraints (through psychophysical or cognitive processes) or a significant degree of culturally–relativistic convention explains perceptual tendencies with regard to categorisation is, as can be seen from the discussions above, a vexed one within cognitive science. The issue is all the more problematic for music due to its complexity as a stimulus form and its context (i.e. it integrates a variety of sensory parameters/modalities at once), so that laboratory studies which constrain this multidimensional complexity may run the risk of losing their ecological validity for explaining representative musical cases. (See Krumhansl (1990, pp.3–9) for discussion of how current research methodology tries to address these conditions.)

Although general theories of musical perception and cognition may be advanced on the basis of experimental findings, the uncontextualised application of these theories to prescriptions regarding potential musical structuring should perhaps be treated with a degree of caution in the context of more exploratory contemporary music. In this regard, there is the danger that these commentaries might reinforce an overly normative model of music, 'bracketing out' significant aspects of exploratory practice (such as microtonality). This may relate to the unmodified application of models which are consistent with the broad aims and values of cognitive science research (and its search for broadly–representative and transferrable general cases within music and beyond) but which are less immediately suited to particular musical cases which may be attempting to create less typical perceptual and cognitive experiences. Gjerdingen (1999, p.167) sees the solution to the creation of a more musically–representative cognitive theory in collaborative interaction between music theorists and cognitive scientists, citing the example the interaction between groups represented by individuals such as Lerdahl (music theorist) and Krumhansl (cognitive scientist) for the theorisation of tonality. However, this examples which he invokes are ones which relate to more generalised models of Western music's common practice rather than exploratory contemporary music.

On this basis, the present account will seek to advance accounts of potential perceptual and cognitive mechanisms for microtonality in the mode of Lerdahl's psychologically–informed music theory, bearing in mind its potential place in the context of a larger interplay between practitioner–informed theorisation and experimentation, in addition to noting a distinction in priorities in relation to the place of exploratory musical practice. In this regard, it is striking that the Miller limit of seven or so elements for a given musical parameter—upon which McAdams (1989) bases his discussion of microtonality (and his general conceptualisation of musical dimensionality)—may be subject to significant capacity enhancement in multiparametric/mulitdimensional musical contexts. In addition, this STM cognitive capacity may be subject to variability based on a more modular/task–specific theory of STM, including the question of whether the phonological loop as a specialised subsystem focussed on auditory events may be partly responsible for better–than–expected perfromance for musically trained subjects. More significantly, however, the phenomenon of categorical perception may play a role in facilitating the processing of music through a limited STM capacity through a multidimensional/multimodal treatment of pitch (thus facilitating some form of chunking arrangement). Whether this occurs due to a largely universalist psychophysical/Gibsonian[181] 'structure–in–the–stimulus' delineation of categories or via more top–down cognitive structures, a multidimensional approach provides the most likely explanation for the treatment of pitch structures which regularly exceed the Miller limit (including microtonality, but also including significantly chromatic musical practices).

5.5 Chapter Summary

This chapter has investigated microtonal music from the perspective of perceptual and cognitive models for the treatment of individual musical intervals. It has critiqued cognitive theories which base their skepticism of microtonality on capacity limitations in short–term memory. The account proceeds to investigate the phenomenon of categorical perception with respect to the perception of pitch intervals, providing discussions of competing bottom–up (sensory/perceptual) or top–down (cognitive) models and further discussing the implications of such theories for microtonal materials. Task–specific ecological factors—which may encourage chunking—are suggested as a potentially significant arbiter of perceptual performance for microtones.

---

[181] See introduction, section 1.3.4, for an overview of Gibson's ecological perception.

Chapter 6: The Psychology of Pitch-Spaces: Structures, Hierarchies, Metaphors and Environments

This chapter continues the development of a theory of microtonality based on psychological models. It investigates cognitively–based factors in the description of relationships between pitch materials and interrogates current theories for their applicability to microtonality. It concludes with the presentation of a framework which describes microtonality based on the integration of perceptually–based or bottom–up factors with cognitively–based or top–down factors.

6.1 From Categories to Spaces

The previous chapter focussed on the question of microtonal perception largely from the perspective of discrete structural elements (individual pitch categories) and the cognitive processing capacities for their treatment implied by current theories of memory structure. Although some introductory contextualisation was provided in relation to how such discrete elements might interact with memory–based elements to facilitate chunking processes or cross–referencing, the approach was primarily atomistic rather than holistic. The models used described the storage of small groups of these elements within STM and the parsing and ordering processes whereby individual elements may be categorised. The theoretical perspective which was broadly favoured was that of the basic bottom–up psychophysical processing for the delineation of category boundaries rather than the possible contribution of structures based on the grouping of these elements to microtonal perception. Thus, we have a theory of microtonal parsing/categorisation (in terms of how categories are delineated and various processes which might explain music's challenging of more restrictive models of STM capacity).

As a by–product of this model, we have highlighted the potential importance of sensory consonance/dissonance cases from the point of view of contributing to the delineation of distinct pitch categories, rather than as a contributor to hierarchical dimensionality (which might contribute to the development of more holistic cognitive 'maps' of tonal relations). However, that there is clearly the potential for a hierarchical treatment of this phenomenon and the concept of hierarchical grouping was the subject of a preliminary discussion in relation to a possible modality by which more culturally–mediated scale divisions such as tempered microtonality might be accounted for in terms of providing a degree of formally–derived hierarchical structure by which to contribute a possible grouping principle for the addition of a 'memory–enhancing' multidimensionality. In summary, the psychophysical approach leaves many questions unanswered as to the form and role of higher–level structures (or structural abstractions) in the perceptual experience of musical pitch. As Shepard (1982, p.306) notes in comparing psychophysical and cognitve approaches, these higher-level cognitive structures are important when the ordering of stimlus materials is based on factors not directly present in the localised/momentary stimulus, as may be the case for sequential musical materials (although, as discussed in relation to Pastore (1987) and Scharf et al. (1987) , psychophysical processes may contribute to the treatment of some sequential presentations).

However, in spite of the presence of the foregoing components of a 'defence' of microtonality from the bottom-up perceptual perspective and their potential contribution to chunking/grouping processes to increase STM capacity, a top-down structuring which transcends invidual elements and/or local levels also has the potential to significantly increase capacity. With this in mind, the present section will examine microtonality from perspectives which transcend that of the individual element, with focussing on potential cognitive models of connections within scale structures.[182]

Transcending the attributes of an individual element entails a range of possible alternatives, some of which have already been approached in the perspectives of microtonal composers and theorists. Microtonal combinations may be viewed as:

(1) Delineating a two–dimensional space based on sensory consonance/dissonance judgements: cf. Partch (1974), Plomp and Levelt (1965) and Sethares (2004)

(2) They may be presented in an immersive/embodied/ecological space based on factors in physical acoustics and psychoacoustics (Young).

(3) They may be structured around a unidimensional but perceptually non-linear space which is nonetheless based on a familiar structural prototype; that of the harmonic series (Tenney, Young).

(4) They may be viewed as delineating complex formal structures which can be described by multidimensional geometric forms tracing procedural/generative connections between integer ratios (Partch, Johnston, Tenney).

Consonance/dissonance judgements clearly have a sensory/perceptual component, as does the immersive presentational approach favoured by Young. This leads to two

[182] Although many cognitive models seek also to describe how different chords and keys are related in musical experience based on common practice functional harmony, these issues are of less immediate relevance with regard to microtonal syntaxes which are likely to be embody somewhat different functional assumptions and approaches; for example, just intonation microtonality tends not to embody the same conception of modulation as common practice Western music does.

questions relating to our present purpose:

(1) Do these multidimensional geometrical structures of specification also have a direct bearing on the basic structuring perceptual experience, beyond their utility as a compositional aid?

(2) Do other models of structural description which have not been treated so far contribute to the perception and cognition of microtonal music?

These questions and related issues will inform the present chapter's discussion of models pitch–space and their microtonal potentials. Although, as Shepard (1982, p.310) notes, the top–down cognitive perspective tends to favour the exclusion of bottom-up perceptual perspectives, treating 'transduction […as automatic and] largely irrelevant', the present account will retain a concern for the the place of bottom–up factors in an overall account. Since the transduction and quantisation process for pitch is not absolute and therefore some of these more basic perceptual features are not completely processed and *abstracted* into categories, this appears to be a sensible approach for microtonal music, especially given the possible delineation of categories on the basis of perceptual features and the influences demonstrated on interval learning capaibilities by Ferrer–Flores (2007).[183]

6.2 Geometric/Spatial Models of Tonal Cognition

6.2.1 Cognitive Models of Pitch

In common with music theorists and composers, psychology researchers have also

---

[183] Indeed, Shepard himself is careful to balance discussion of cognitive organisation of categories with discussion of their possible psychophysical genesis, such as his discussion of perfect fifths (Shepard, 1982, p.312), whilst nonetheless asserting that *purely* psychoacoustical investigations of pitch (especially those which utilise less ecologically valid pure-tone stimuli) do not do justice to its salience in musical contexts.

attempted to define models of how tones are related to each other. A particular focus has been how the apparent 'continuum' of pitch–space is divided up and how individual elements within this division are related to each other: i.e. searching for psychological 'distance factors' between pitches which are not simply the result of stimuli being close in the physical dimension of frequency. In relation to this imperative, the products of such investigations bear some resemblance to the the multidimensional formal models discussed in chapters three and four. The fields of emprically–based music cognition—for, example, the work of Krumhansl (1990) and Shepard (1982)—and cognitively-informed music theory—e.g. (Lerdahl, 2001)—have sought to investigate the presence and nature of these putative structures. The major focus has tended to be on common practice Western music[184]; the cognitive scientists tend to be performing their research within the context of Western culture and the music theorists are equally, if not more, conceptually invested in this musical culture through their training. As Krumhansl (1990, p.15) notes, Western music's tonally–based hierachy is relatively easy to study in experimental terms, especially given its extensive body of theorising, which may facilitate and inform the efficient experimental exploration of the field through predictions based on these theories. In addition, Krumhansl opines here that the organisational principles for the microcosm of Western music appear to parallel general cognitive organisational principles, so that they are, at the very least, special cases of more general cognitive univerals.[185]

[184] Although Krumhansl (1990, chapter 10) does provide an account of experiments which investigate tonal hierarchies in music from outside the common practice: serial music and North Indian music, finding some strikingly similar (in comparison with Western common practice music) tonal relations judgements for the latter. However, microtonality is not studied.

[185] However, this still does not necessarily imply that the particular musical special cases found for Western common practice music are applicable without any modification to other musical forms.

6.2.2 Octave Equivalence, Pitch–chroma and Helical Representations of Pitch–space

The search for multidimensional models which could be endoresed by empirical subject testing initially focussed on the phenomenon of *octave equivalence*, whereby there is a universal/near-universal tendency to equate pitch materials separated by octaves or compound octaves. Shepard (1964) investigated this phenomenon of greater psychological proximity. He reprised a proposal by Drobisch (1846, cited in Shepard, 1964, p.2346) that octave equivalence be accounted for through a helical representation, modelling this proximity and splitting pitch into two component dimensions for *pitch–height* (absolute physical distance of frequency stimuli) and *pitch–chroma* (for psychological difference within the context of a pitch–space bounded by the octave).[186] This model is visualised in figure 44 (below, next page). Shepard (1964, pp.2347–53) verified this theory through the creation of a synthesised sequence of tones which were ambiguous in their difference on the pitch-height dimension (through the deployment of octave-only partials in the source timbre which were progressively enveloped at the higher and lower ends of the spectrum such that movements in the pitch-chroma dimension led back to spectrally identical cases at the octave).[187]

---

[186] Krumhansl (1990, p.111) provides a survey and commentary on a number of similar approaches for modelling tonal relationships.
[187] This stimulus configuration is now popularly known as the 'Shepard tones'.

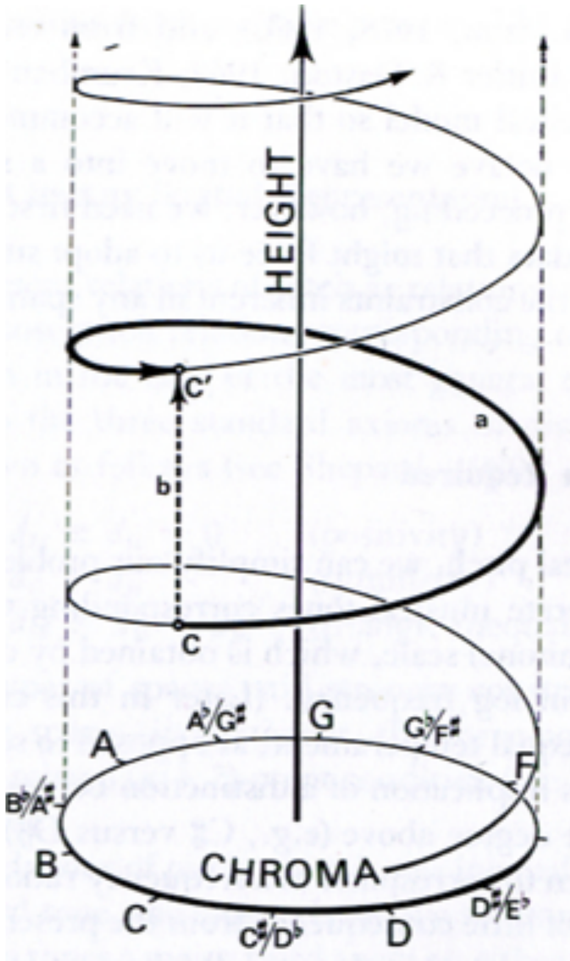


Figure 44: Shepard's model of the dimensionality of pitch-space in terms of separate dimensions for pitch-chroma and pitch-height, from Shepard (1982, p.353).

As can be seen from the above diagram, the delineation of pitch–chroma is based on its division into a circle with chromatic 12TET intervals embedded in an anticlockwise fashion (although enharmonic conflation is indicated). However, the model has no direct bearing on the perception of microtonal materials as distinct from the modelling of any other within–octave structures; additional microtonal intervals could easily be accounted for. Nonetheless, it provides an important example of emprical verification of spatial models of musical pitch proximity for axes beyond the immediate adjacency of intervals. In this regard, the question may be asked whether other non-adjacent relationships between intervals may be subject to generally–applicable cognitive structures. Shepard (1982)—see figure 45, below, next page—goes on to model what he terms the 'heightened' relationships between pitch–chroma intervals and structures which are commonly found in Western musical practice: scalar structures such as diatonic, whole-tone and chromatic scales (pp.314–9) and functional connections such as perfect fifths (p.312).

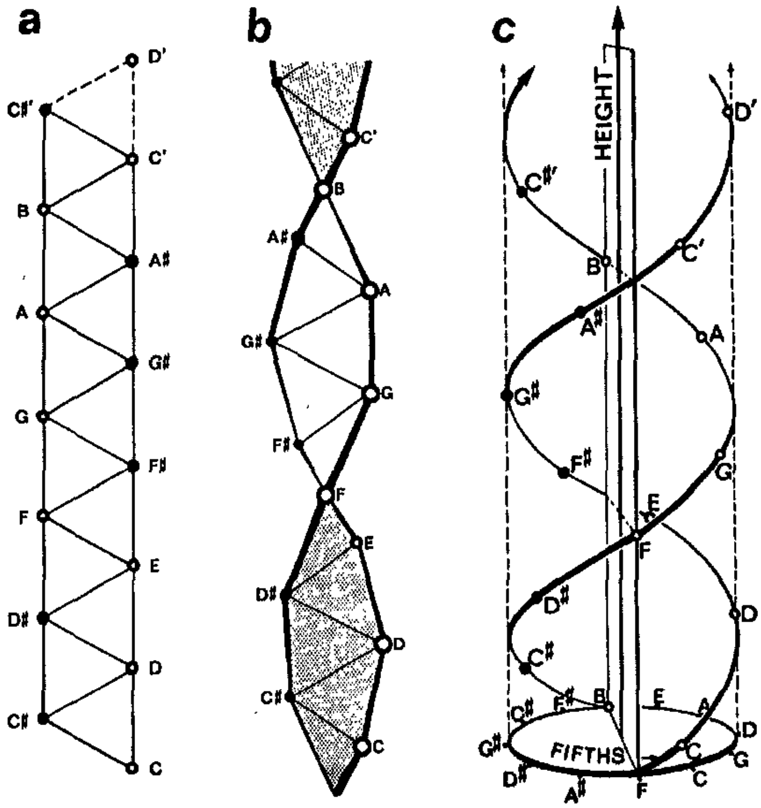


Figure 45: Shepard's 'double-helix with cycle of fifths' cognitive model of dimensionality within musical pitch, encompassing pitch-height, and pitch-chroma subdivided into whole-tone and musical fifth connections, from Shepard (1982, p.362)

Parts (a) and (b) of the figure above demonstrate the development of a pitch-chroma double-helix which encompasses diatonic and chromatic structures, which is then mapped onto a circle of fifths in the horizontal plane

However, for Shepard, this model is not sufficiently 'robust' in its foregrounding of pitch–chroma relationships, leading him to further elaborated by a the mapping of pitch–chroma connections to a torus (p.319-20), see figure 46, below, which embeds cyclical structures for fifth-based and stepwise relationships.[188]

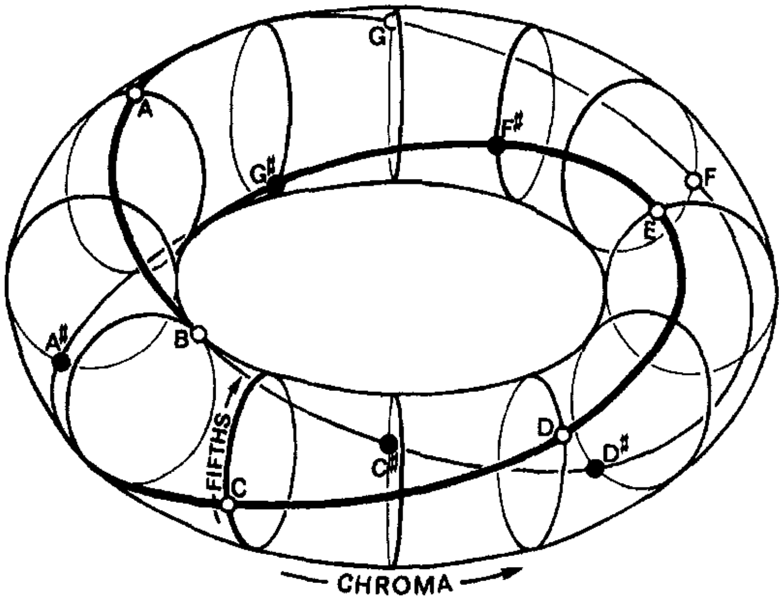


Figure 46: Toroidal representation of pitch–space, from Shepard (1982, p.319), highlighting pitch–chroma relationships for scalar and fifth–based structures (and removing pitch–height for efficiency of representation)

These models provide formal descriptors of a range of functional musical relationships and may provide the key to how pitch materials are parsed such that the limited capacity of STM is not such a significant barrier to the cognition of relatively extensive musical structures. None of the models discussed thus far expressly prohibit microtonal materials—adaptations to include these subdivisions could conceivably be added with relative ease—but the models are nonetheless based on common practice Western music

[188] In addition, Shepard (1982, p.321) devises a hybrid of the torus and the double-helix; this is to achieve a model which benefits from detailed treatment of pitch-chroma whilst still preserving possibilities in relation to pitch-height distinctions. Nonetheless, given the broad (and robust) efficacy of octave equivalence, for the sake of a parsimonious representation this elaboration is not significant for our present purposes.

do not provide any explict basis for the endorsement of microtonal subdivisions of chromatic pitch categories. Shepard (1982, p.313) does briefly mention the Miller limit in a discussion of the background to scale structure, but as discussed above, this limit appears not to apply to musical pitch capabilities in more typical musical situations, possibly due to hierarchical structuring facilitated by bottom-up psychophysical factors or top-down cognitive structures such as those proposed by Shepard.

6.2.3 Beyond the *Tonnetz*/Lattice: More Accurate Modelling of Perceived Distances/Hiearchies in Tonal Relationships in Krumhansl (1979) and Following

As noted above, Lerdahl (2001) addresses the cognition of pitch from the perspecitve of creating a cognitively–based music theory. His introductory historical survey (Lerdahl, 2001, pp.41–6) covers a range of pitch–space models, including the helical forms of Drobsich and Shepard and the lattice structures (or *Tonnetz*) of Euler/Riemann et al. Lerdhal subjects the latter form to a significant degree of scrutiny in terms of its applicability as a model of tonal cognition, complaining that:

> […] its distances are empirically incorrect. In a C major context, one does not hear, for example, the pitch F as closer to the tonic than D or A*b* as closer than A.
>
> (Lerdahl, 2001, p.45)

From this perspective, it is more useful as a formal rather than a cognitively–accurate musical description. Lerdahl (*ibid*., p.84) further diagnoses what he sees as the main problem with this type of representation as being a prioritisation of simultaneous harmony over sequential/scalar structures which themselves form a significant basis of musical construction. In addition, Krumhansl (1990, p.114) has referred to another (related) issue in such models, that of enharmonic equivalents, which may alter tuning, leading to representations in this form which are designed to accurately reflect integer-based tunings which are open rather than closed at the octave limit and thus do not provide the opportunity for a compact rendering of pitch–chroma proximity. Also, Krumhansl (1990, p.119; Krumhansl and Kessler, 1982, p.347) has noted that the question of perceived distance in such regular geometries is particularly problematic in cases where materials are presented in melodic context, as the hierarchical implications of tonality may cause the same interval size with a different starting point to exhibit differing strengths of relationship to a tonal centre. Thus, the dimensionality of the basic *Tonnetz*/lattice structure does not account for the variable psychological proximity or distance which scale structures apply as modification to fifth–based modulatory functional dimensions in common practice Western music, making it an incomplete model (in terms of psychological distance) of direct intervallic connections other than these two interval types. Lerdahl notes that the research project of Krumhansl (1990) provides an empirically–grounded solution to this problem which conforms to previous music theories of inverval hierarchies, such as those of Meyer (1956, cited in Lerdahl, 2001, p.45). Krumhansl and Shepard (1979, cited in Krumhansl, 1990, pp.18–9) used a *probe–tone method* to investigate tonal hierarchies by presenting an incomplete diatonic (major/minor) scale ending on the seventh, followed by the entire range of possible 12TET chromatic divisions (the *probe tones*), asking listeners to judge and assign a magnitude for 'completeness', thus providing a judgement for what might be termed *functional salience* of intervals.

One factor which is notable for the present purposes is that (quartertone-based) microtonal stimuli were also tested by Krumhansl and Shepard, but did not produce significantly lower values[189] than those obtained for 12TET divisions (p.21). As such, this research appears to cast some doubt on the cognitive 'validity' of microtonal distinctions.[190] However, it should be noted that timbral (in terms of spectral) factors were eliminated to a greater or lesser extent through the deployment of stimulus tones using the flute setting of an electronic organ in one experiment and in using computer-generated sinusoidal tones in the other (p.21); the experiments thus provide the opportunity for top-down processes to dominate, although at the expense of cues which may be used in interval recognition[191]; see discussion of the research of Ferrer–Flores (2007), above. However, Jordan (1987) used a similar experimental method (probe-tones and scales with sinusoidal waveforms) and found microtonal distinctions to be present at the quartertone level. This effect may not be particularly robust; Krumhansl (1990, p.22) surmises that the effect might be present in Jordan's work due to the presentation of scale and probe stimuli in the same octave (in contrast to her own study). Jordan (1987, p.486) did not find significant differences for the eighth-tone level. Nonetheless, microtonal scale materials been found to be cognitively salient even in a context which minimises potential bottom–up contributions; as noted above, the use of more ecologically–valid harmonic timbres may improve performance in 'real world' cases.

However, Krumhansl's account of tonal geometries does not pursue microtonal cases

---

[189] Krumhansl notes that they were found to approximate the average of adjacent 12TET values.
[190] Krumhansl and Shepard (1979, p.591) invoke the Miller limit as an explanation for this finding.
[191] This is not a criticism of the experiment's design, which sought to discern the structure and strength of the tonal hierarchy from a purely top-down perspective, but it does mean that 'real world' cases might entail improved performance for microtonal intervals such that they would produce significantly different values. See discussion in Gjerdingen (1999) for treatment of the convergence and divergence of interests for psychology and music theory.

and, in particular, favours categorical reduction through enharmonic equivalents so that within–octave psychological distances for pitches may be represented in a compact fashion, noting this as an advantage of reducing the number of ‘distinct pitch categories’, in addition to appealing to the authority of the ‘general acceptance of equal-tempered tuning’ (Krumhansl, 1990, p.115–6). As noted above, the question of representing tonal distance judgments in a regular geometrical model is considered to be problematic. A particular issue is that tonal relations may vary significantly with direction; e.g. the difference in ‘coherence’ between *B* moving to *C*, versus *C* moving to *B* (Krumhansl, 1990, p. 121). As Krumhansl notes (p.123), geometrical models are necessarily symmetrical in terms of their representation of distance between two nodes; therefore, this asymmetrical ‘psychological distance’ factor is particularly problematic. However, it was found in the study of Krumhansl and Shepard (1979, p.358; Krumhansl, 1990, p.127) that these contextual and aysmmetrical ‘psychological distance’ effects were clearly related to the same overall tonal hierarchy judgements, but with a different scaling factor based on the order (with the second or final interval being accorded greater ‘weight’). As such, Krumhansl notes here that an order-independent representation could be constructed by averaging values for both directions for individual intervals.

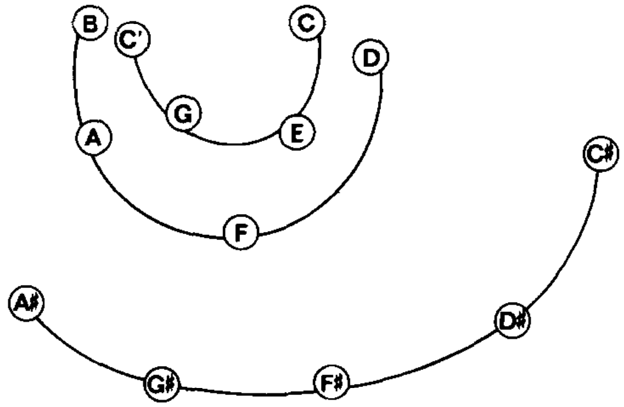


Figure 47: Two-dimensional graphic representation of tonal similarity/hierarchy judgements obtained using multidimensional scaling, from Krumhansl (1979, p.356)

As can be seen from figure 47 (above), graphing similarity judgements reveals a hierarhical structure which is quite familiar in terms of its division: a triadic level, a level for other diatonic tones and a level for non–diatonic tones. This hierarchy becomes even more apparent when a multidimensional scaling process is applied; these judgements produce a relatively simple cone when represented in three dimensions (Krumhansl, 1979, p.357; Krumhansl, 2005, p.9); see figure 48, below.[192] As can be seen, this cone (in common with figure 47, above) takes the broad form of an 'exploded' pitch–chroma circle and is thus broadly consistent with earlier models of pitch–chroma.

[192] Krumhansl and Kessler (1982, cited in Krumhansl, 1990, p.125–6) used two different cones for the representation of major and minor modes. However, for brevity, the present discussion will focus on the implications of the major mode model.

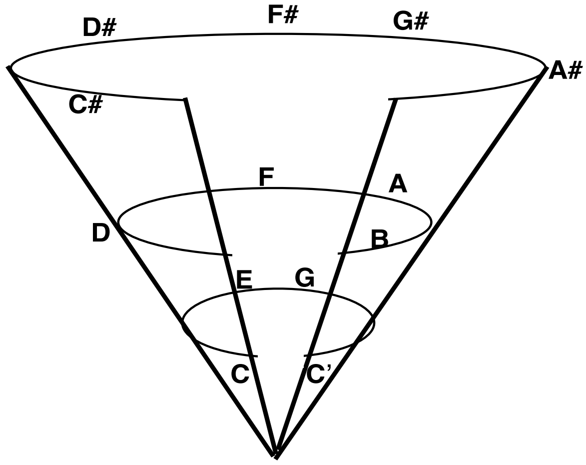


Figure 48: Idealised tonal hierarchy cone (based on multidimensional scaling results) for C major for all 12TET chromatic pitch-classes, after Krumhansl (1979, p.357); see also Krumhansl (2005, p.9),

The tonal hierarchy findings for this particular experiment (Krumhansl, 1979, p.355) were somewhat more consistent than those found in the previous experiment of Krumhanlsl and Shepard; subjects all had a consistent minimum standard of training (at least five years) in Western common practice music. The experimental procedure was, as before, based on providing a ‘priming’ scale, followed by the two tones which were to be queried for ‘distance’ (Krumhansl, 1979; Krumhansl, 2005, p.9). Krumhansl (1990, p.26) herself notes that the reason for the choice of subjects was to decrease the chance that what she terms ‘non–musical’ strategies would be applied to the hierarchical judgements, such as simple assignment on the basis of pitch–height. This aspect has been criticised as a sort of tautological ‘theorism’ by Cook (1994, cited in Cross, 1997, p.350), although Cross (1997, p. 350) notes that the studies of North Indian music discussed later in Krumhansl (1990) provide a validation of the general Krumhansl model for an unfamiliar musical style.[193]

6.2.4 Extended Functional Levels and Microtonal Hierarchy Judgements: Commentary on Jordan (1987) and Krumhansl (1979)

As noted above, the overall scale structure prioritised by Krumhansl was that of the standard 12TET chromatic scale; this is a perspective which persisted in later studies in spite of the effects found by Jordan (1987) for quartertones. In this regard, the question could be asked as to what extent a hierarchical structure for microtonal interval categories is conceivable within the context of Krumhansl's overall model? In addition, a further question could be asked regarding the source of these interval categories and its possible contribution, i.e. are they in any way similar to the attributes of the harmonic series? Examining the first question, Jordan's group of musically-trained subjects found the values depicted in figure 49 (next page) for ascending and descending interval presentations (which are relatively consistent for ascending and descending modes). These results also show significant differences between the microtonal and adjacent non-microtonal intervals. These figures imply that the Krumhansl cone could be extended to another level which would account for figures of around 2 on the 7–point 'distance' scale for the microtonal 'additions' in comparison with figures of around 3 for the chromatic divisions which are not found within the major scale (i.e. non–diatonic tones).

[193] However, whether subjects are intimately familiar with Western musical conventions or have only had a passing/passive exposure to it, tonal hierarchy judgements still have a relative degree of consistency for listeners, as can be seen by the figures in (Krumhansl and Shepard, 1979, p.586). These show some similarity between expert and non-expert groups in their judgements of tonal relations for the position of peaks of 'relatedness', if not for their magnitude.

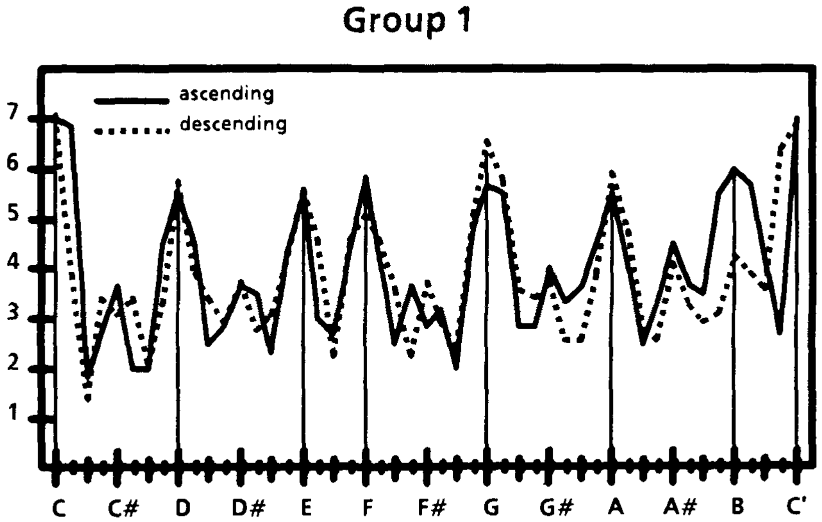


Figure 49: Judgements of musically-trained listeners for hierarchical importance of microtonal intervals, from Jordan (1987, p.484).

Thus, Krumhansl's cone representation of 12TET pitch class hierarchy could be expanded to another level on the basis of the Jordan (1987) results being broadly compatible with those of Krumhansl (1979), which found average figures of around 3 for its outer 'layer'. As such, an adapted version of this figure is sketched[194] below in figure 50, next page. Approximate 'distance' values are provided on the y axis for indicative purposes. One interesting factor in the Jordan data is the higher position for the quartertone interval above *G* (between 3 and 4), which is much higher than the other quartertone offsets. Whilst still providing a rating which is distinct from the perfect fifth, it enjoys a rating which is commensurate with the intervals of the 'chromatic level'. A similar effect is also found by the quartertone above *B*.

[194] The somewhat higher ratings for *E* as opposed to *D* in the Krumhansl study are retained.

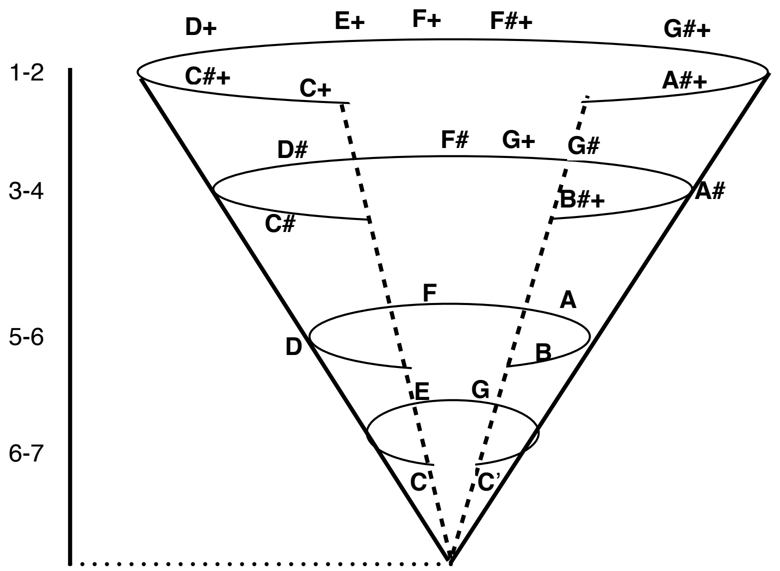


Figure 50: Possible 24TET microtonal extension of Krumhansl's (1979) pitch–hierarchy cone, adapted using data from Jordan (1987)

6.2.5 A Cognitively–Based Music Theory of Tonal Hierarchies (Lerdahl, 2001)

An alternative form of tonal hierarchy was proposed by Deutsch and Feroe (1981, cited in Lerdahl, 2001, p.45), which proposed organising pitch–space by a hierarchical algebraic representation; as Lerdahl (2001, p.45) puts it, an 'alphabet' rather than a geometric figure, with different levels of articulation at the octave, triadic (plus seventh), diatonic and chromatic levels. He further notes here (*ibid.*) that this division is broadly similar to Krumhansl's structural division.[195] Upon this basis, Lerdhal elaborates a version termed the *basic space,* describing intervallic relationships (figure 51, next page), which is mediated by various considerations relating to common

[195] Although a separate level for the octave is not provided in Krumhansl's model and each new level does not provide a complete restatement of the pitch set from earlier levels.

practice music: fifth and thirds are assigned separate/additional levels, with the seventh excluded from the Deutsch and Feroe's triadic level, although Lerdahl notes it could be reinstated 'if judged to be harmonic', which is consistent with practice in extended just intonation. Nonetheless, the removal of the seventh brings the model closer still to Krumhansl's. However, the separation of the 'octave plus fifth' level does mark a relatively more significant alteration from Krumhansl's empirical results: factors for major third and fifth are very close in Krumhansl (1979, pp.355–6), although the third is more of an outlier (see figure 47). Although this structure contains no explicit treatment of micrtonal strutures, Lerdahl's account will be examined in the context of its possible insight into structural features which might contribute to an explanation of the structured cognition of microtonal intervals.

Level a: octave

Level b: octave plus fifth

Level c: major triad (with seventh if harmonic)

Level d: diatonic major

Level e: (12TET) chromatic

Figure 51: Lerdahl's 'Basic Space' for hierarchical organisation of pitches, after Lerdahl (2001, p.47)

On the basis of this model, Lerdahl (pp.48–9) provides an analysis of its procedural mapping, which embodies a hierarchy which broadly parallels Krumhansl's; see figure 52 (below, following page).

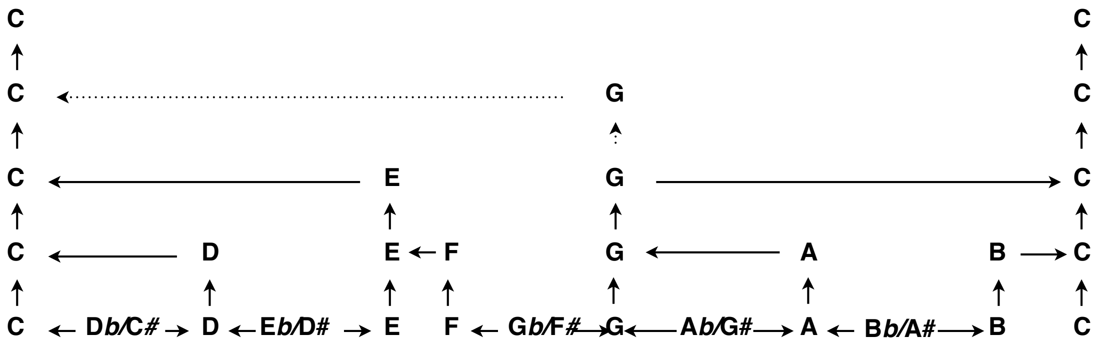


Figure 52: Functional connections for different levels of 'basic space', after Lerdahl (2001, p.49).

As Lerdhal notes (*ibid.,* p.48), this framework is congruent with musical practice in terms of modelling standard musical figurations in Western music: arpeggiations, octave leaps and movements by fifths can be conceptualised as stepwise motion at their particular functional level. As such, it corroborates the model's consistency with functional approaches typically found in common practice Western music. More importantly for the present purposes, he also asserts that it embodies the empirical data in its multi–levelled step–wise movement, providing an analysis of the number of steps of horizontal and/or vertical movements within this procedural 'space' are required to reach the root/octave level, represented in terms of pitch classes (figure 53, below, next page). Interestingly, the representation embodies a degree of implicit structural microtonality through its incorporation of enharmonic distinctions; different enharmonic intervals are accorded distinct hierarchical weightings due to the number of procedural steps required to reach the lowest level; thus, a further *enharmonic* level (with eighteen discrete—though unequal—divisions) could be conceivably be extrapolated from the chromatic level. However, in broader terms, it is striking that the procedural distances illustrate a relative corroboration of the Krumhansl's (1979) similarity judgements by the ratings obtained through this formal model; if the vertical distance ratings are inverted in the present model (i.e. becoming 'similarity to *C*/pc0' by subtracting ratings from 7). The parallel is striking: Krumhansl's hierarchical values are broadly replicated, albeit in relative approximation: 7 for *C*, 6 for *G*, 5 for *E* (which had been an outlier in the original findings), 4 for the diatonic level and 3 for the chromatic level (the exact numerical values are out of alignment at this point, but relative positions are preserved). Thus, the procedurally–derived ratings, whilst not identical, nonetheless support a multi–levelled grouping which is similar to that of Krumhansl (1979).

(a) Horizontal distance from root/pitch class zero (pc0)

Triadic Space

Pitch	0	4	7	(0)

Diatonic Space

Pitch	0	2	4	5	7	9	11	(0)
Distance	0	2	4	5	5	3	1	(0)

Chromatic Space

Pitch	0	1	2	3	4	5	6	7	8	9	10	11	(0)
Distance	0	1	2	3	4	5	6	5	4	3	2	1	(0)

(b) Vertical distance from root/pitch class zero (pc0)

Chromatic Space

Pitch	0	1	2	3	4	5	6	7	8	9	10	11	(0)
Distance	0	4	3	4	2	3	4	1	4	3	4	3	(0)
'Similarity'	7	3	4	3	5	4	3	6	3	4	3	4	0

(c) Combined distance from root/pitch class zero (pc0)

Chromatic (enharmonic) space

Pitch C D*b*/C# D E*b*/D# E F G*b*/F# G A*b*/G# A B*b*/A# B C

Distance 0 5 6 4 6 6 3 5 7 6 2 6 7 5 7 6 4 0

Figure 53: Illustration of procedural/functional 'distances' in Lerdahl's 'basic space' model, after Lerdahl (2001, p.49)

Lerdahl now completes the circle by mapping these values to a pitch–class cone[196] which embeds hierarchical (i.e. vertical) distance and horizontal adjacency (see figure 54, below), although, since it uses pitch–classes, this cone does not embed the complicating factor of enharmonic distinctions discussed above.

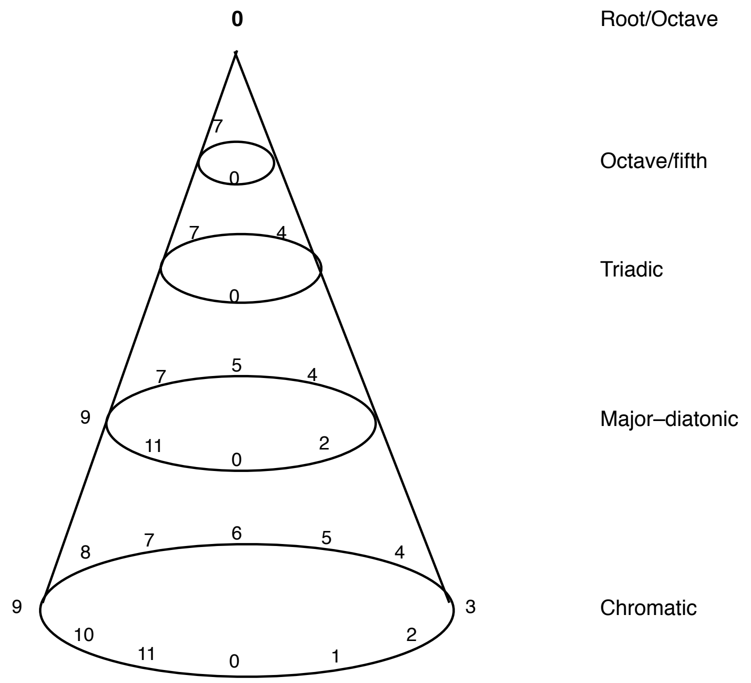


Figure 54: Lerdahl's pitch–class cone and functional division of pitch–space; after Lerdahl (2001, p.50)

One potential parallel of this structure, which is revealed through the separation of fifth and triadic levels, is its similarity to the organisation of the early intervals of the harmonic series. This is broadly consistent with Krumhansl's (1990, pp.55–7) comparison of sensory consonance values with her tonal hierarchy studies for major key profiles. In addition, the similarity between harmonic series intervals and musical scale

[196] Lerdahl (2001, pp.74–80) goes on to further develop this model into a dynamic account based on common practice tension–and–release structures: however, as this is more specifically related to common practice music, it will not be discussed here.

definition and functional structures is a common one in Western music's theoretical discourse; one such example is that of Schoenberg (1922, pp.320–322), discussed in chapter one, along with the scientific accounts of Helmholtz (1863), Plomp and Levelt (1965) and Terhard (1978). However, these accounts are confined to discussions of scale structures on the basis of bottom–up perceptual attributes derived from the structure of the harmonic series. They do not provide a detailed hierarchical framework which purports to depict cognitive relationships, as the figures above do. Thus, the potential similarity between the harmonic series as perceptual phenomenon and cognitive structures related to hierarchical judgements provides an intriguing suggestion that this may be a case of bottom-up ecological perception (a section of Lerdahl's (2001, pp.80–81) account will be discussed below in relation to potential sensory-structural and psychophysiological bases for the different functional levels).

6.2.6 A Potential Model of Ecologically–Derived Cognitive Structuring for Pitch Hierarchies

These sensory–structure/functional–division parallels are observable in an adaptation of the Lerdahl/Krumhansl–style cone to the harmonic series (figure 55, below, next page), with separate circular pitch–chroma circles for different octave 'levels' (harmonic positions on this pitch–chroma circle are approximated somewhat for graphic clarity).

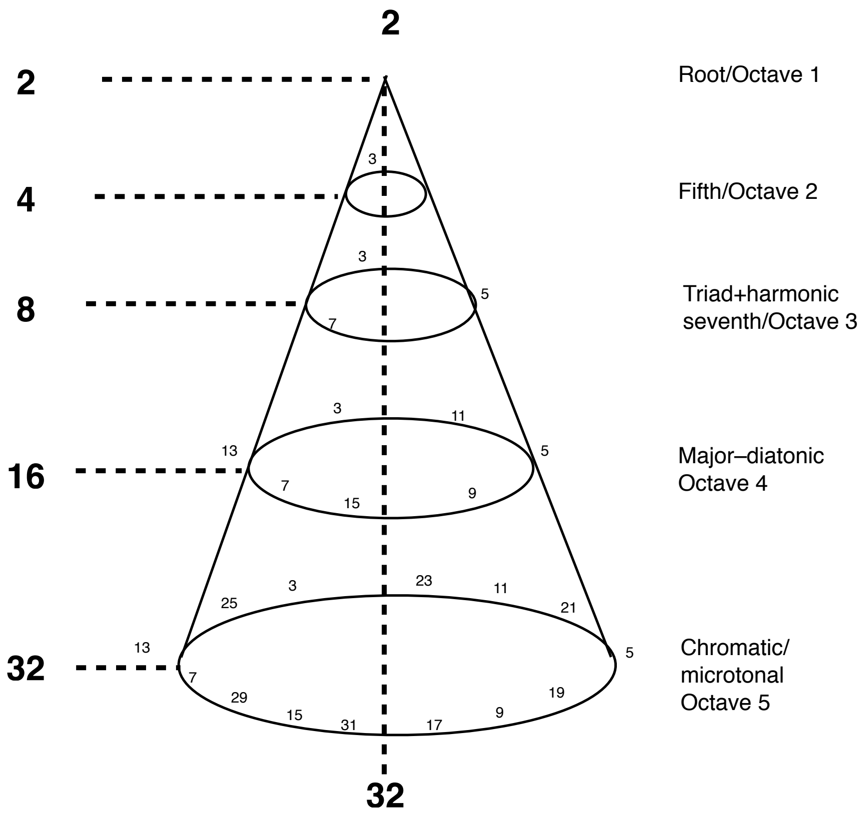


Figure 55: Mapping the first five octaves of harmonic series intervals to a cone–shaped representation (octave intervals are indicated on the pitch–chroma circle by the central vertical line)

As can be seen, in the harmonic series, the root/octave 'level' is followed by a fifth in the second octave and the major triad (with the addition of the harmonic seventh, which Lerdahl had previously removed while altering the Deutsch/Kessler model to preserve consistency with common practice) in the third. The following octave contains variants of the main diatonic intervals (with the addition of the 11th harmonic and the ommission of the perfect fourth[197] which, though similar, differ by about a quartertone), with minor sixth provided by the 13th harmonic, along with the addition of a harmonic major seventh (15th harmonic). The next octave introduces some more chromatic/enharmonic intervals such as the 17th harmonic as semitone, 19th harmonic as minor third, 27th harmonic as major sixth, 21st harmonic as a diminished fourth and 23rd harmonic as an augmented fourth. Variants on the harmonic and major seventh are also introduced (29th and 31st harmonics). Although there are divergences in tuning for a number of these intervals at the diatonic and chromatic/enharmonic 'levels', it could be argued that the divergence between the harmonic series intervals and those of the pitch-class cone is simply due to the rationalisation/standardisation in Western music which codified the 12TET scale structure (and functional differences with regard to the use of the harmonic seventh).

Thus, although Lerdahl has elucidated the *formal properties* which could contribute to the generation of this structure, its overall arrangement nonetheless bears a striking resemblance to an ecological and perceptual phenomenon, i.e. the broad organisational structure of the early harmonic series. This raises questions regarding the possible source of the cognitive structure: is it directly based on perceptual properties within stimlus materials (i.e. the structure harmonic series) or is it an emergent structure due to the potential formal relationships orcodification of hierarchical relations based on usage conventions for culturally–derived scales (which were, perhaps, originally influenced by the harmonic series)? Labelling these cases respectively as *bottom–up* (perceptually–

[197] The perfect fourth is more plausibly obtained as a 'generated' interval by moving downwards by a perfect fifth. Krumhansl (1990, p.57) notes that this interval is an anomaly when comparing her cognitive hierarchy with sensory consonance values.

based) and *top–down* (higher–level cognition), if the former, it is entirely coceivable that microtonal intervals from higher regions of the harmonic series may be perceived hierarchically.[198] If the latter, the cognitive salience of microtonal divisions of at least the quartertone level of quantisation has been demonstrated by Jordan (1987). Both potential explanations for the hierarchical models discussed above suggest that music which exceeds the Miller limit may be not be as prohibitatively difficult to perceive and remember as previous commentators such as McAdams (1989) have sometimes considered it to be.

6.3 Perceptual/Ecological and Heuristic Models of Tonal Cognition

6.3.1 Bottom–up Perceptual/Ecological Models

These cognitive models of musical pitch—Krumhansl (1979; 1990) and Lerdahl (2001)—assume that such cognitive structures must be generative structures which are *mediated* (and *mediating*) structural abstractions which 'filter' perceptual experience (in terms of categorisation and relationship between categories, hence 'mediating'). These abstractions may be formed due to our encounters with perceptual phenomena in our environment, but are nonetheless codified as (emergent) abstractions based on long–term exposure and learning rather than being primarily based on *relatively unmediated* environmental structures. As such, these cogntive models are arguably better equipped to describe man–made/cultural perceptual constructs (particular broad cultural cases of

[198] Although these may be subject to limiting factors based on stimulus discriminability and categorical perception, a potential 'bottom–up' explanation for the latter being provided by Pastore's (1987) account of a psychophysical model of CP (discussed in the previous chapter).

music, such as those found in Western music and others with similar scale structures) rather than being based on an environmental model which is unmediated by musical convention. However, as noted above, these abstracted cognitive models could be viewed as being structurally similar to the environmental phenomenon of the harmonic series. Whatever the origin of such a similarity (be it primarily based on a emergent formal properties and/or cultural usage conventions[199] or be it a relatively unmediated environmental template), the pronounced structural similarity does suggest that bottom-up perceptual factors could play a role in defining the structure of cognitive musical experience. The present section will follow this thread to investigate possible explanations (and implications) for cognitive musical structures which are broadly related to environmental experience.

6.3.2 Perceptual Commentary in Lerdahl (2001): Psychophysical Divisions as Functional Structures and Bottom-up Attentional Effects

Lerdahl (2001, p.80) does take particular note of perceptual issues (in terms of psychophysical and structural influences) in part of his account and discusses the correlation between 'psychoacoustically–related stylistic features' and different levels of potential functional articulation, initially through the identifying the basic increase in sensory dissonance at each successive level. More particularly, he invokes the Terhard (1974, cited in Lerdhal, 2001, p.80) model of pattern–matching to a harmonic template (considered as overtones in relation to the root or virtual pitch at what he terms *level (a)* (root/octave); see figure 51, above. In addition, he posits (*ibid.,* p.81) a psychophysical

[199] Which modify the basic environmental template structure which provided the original basis for scale structure.

explanation for the division between triadic and diatonic functional levels, based on the critical band response (Plomp and Levelt, 1965, cited in Lerdahl, 2001, p.81). As Lerdahl puts it:

> In the basic space the intervals at levels a–c [i.e. (a) root/octave, (b) fifth and octave and (c) triadic] lie outside the critical band, in consequence of an aesthetic ideal of harmonic euphony that existed throught much of Western music. Indeed, the various triads (major, minor, diminished and augmented) are the only trichords that meet this condition.
>
> (Lerdahl, 2001, p.81)

Lerdahl further notes that the diatonic and chromatic levels (which give rise to pitches which fall within a critical bandwidth) give rise to melodic structural and 'inflectional' possibilities. Given the aforementioned 'aesthetic ideal of harmonic euphony', the non-root-triad diatonic and chromatic notes clearly produce perceptually distinct cases of relative sensory dissonance, consistent with Lerdahl's (*ibid.,* p.80) theory of correspondance of increasing sensory dissonance with functional level (thus contributing to the development and codification of a functional consonance/dissonance oppositional axis, cf. Tenney's CDC-IV theory (Tenney, 1988). The use of these levels for melodic materials could thus be posited on their relative sensory and functional instability, resulting in relatively fast-moving melodic structures which do not remain at rest on non-triadic diatonic or chromatic intervals for long. Another possible explanation, which Lerdahl (2001, p.81) favours is that of bottom-up perceptual proximity effects. He references the theory of a *perceptual attention band*[200] (Scharf et al., 1987, Bharucha, 1996, cited in Lerdahl, 2001, p.81), , coincident with the critical

[200] See discussion in the previous chapter in the context of Pastore's model of psychophysically–based CP.

band, which may cause listeners' attention to focus on pitches within this range to the exclusion of those outside producing what Lerdahl refers to as a 'kind of [perceptual] glue' for melodic structures, encompassing standard diatonic, chromatic and (potentially) microtonal steps sizes. Thus, the 'perceptual glue' of this type of effect may contribute to the emergent sense of virtual continuity which is a property of melodies, and the more finely–grained perceptual attention processes may further contribute to what Lerdahl (2001, p.81) terms 'inflectional possibilities' at his chromatic level.

If the attention band hypothesis is correct, the inflectional possiblities of this level might include some salient microtonal distinctions. Lerdahl is careful to add a moderating note here that there is 'nothing obligatory' about the aesthetic use of a model based on basic perceptual features; nonetheless, as discussed previously, the preference for this type of sensory configuration appears to be embedded in a wide range of global musical practices which utilise relatively sustained articulations using harmonic timbres. A standard feature of a broad range of musical 'models' may derive a significant perceptual/cognitive coherence from the exploitation of these bottom-up perceptual strategies.

6.3.3 Heuristic Alternatives to Fixed Hierarchies (Butler, 1989) and Related Critiques of Krumhansl (1979)

A less static model of hierarchical relationships between pitch materials has been proposed by Butler (1989), who suggests that the Krumhansl (1979) model of a fixed tonal hierarchy (in modal/scale–structure context) may be deficient in a number of respects. Butler (pp.230–231) questions whether the model's structure may be the emergent result of particular 'priming' melodic patterns used as test stimuli rather than providing a generalised model of tonal relations, which he illustrates through a comparison of a statistical graph of frequency of tone occurences in comparison with a major–key tone profile from Krumhansl and Kessler (1982). The basic modality for this influence proposed here by Butler is that some of the tonal materials persist as residual contextual influences on short–term memory.

Cross (1997, p.346) notes a further possible potential influence which is bottom–up: that of basic Gestalt–style principles of 'good continuation' (Bregman, 1990, cited in Cross, 1997, p.346) providing a modality for assessing the salience/relevance of a particular tone as conclusion to the 'incomplete' priming stimulus.[201] Apart from this issue of the potential relationship between stimulus materials and cognitive structure, a central aspect of Butler's (1989, pp.223–4) general critique of Krumhansl's approach is his issue with the static rather than contextualised/adaptive nature of the Krumhansl hierarchical model, such that it provides no information about musical experience at a

[201] In other words, the only 'hierarchy' needed to parse a melody is whether it fulfils or contradicts expectation of continuity at a local level; this is an elegantly 'ecological' explanation of 'structure in the stimulus' and could conceivably have been a factor in some of the experimental findings of Krumhansl.

more localised level within a piece, i.e. particular/momentary note–to–note relations 'in musical time'.[202] More fundamentally, Butler takes issue with the focus on scale structures, opining:

> Although the extent to which the theory–building and methodology of psycholinguistics can serve as a model for the cognitive study of music is still unclear, it certainly is clear that major revelations of "deep structures" in grammar did not issue from repeated and careful studies of the alphabet. (Butler, 1989, p.233)

As can be seen, Butler does not regard the (relatively fixed) scale structures and the (related) fixed model of tonal hierarchies as particularly cognitively relevant, as opposed to a more localised and dynamic model (*ibid.,* pp.238–40) of *intervallic rivalry*. This is described (*ibid.*) as a relatively compact set of rules (which is taken to explain the relative ease and speed with which listeners make judgements relating to tonal coherence; an 'act of perceptual orientation', as Butler puts it), the result of a number of cases which are effectively reducible to the statement: '[a]ny tone will suffice as a perceptual anchor—a tonal center—until a better candidate defeats it.' The result is a more stylistically–specific model which relates listeners' judgements not only to fixed tonal hierarchical relations (within a particular familiar style) but also to local–level features such as familiar structural features such as cadential figures and frequency and duration of notes which corroborate or alter the adjudged tonal centre dynamically. Cross (1997, p.348) provides a particularly clear statement of these

[202] Although Lerdahl's (2001) model of pitch–space adds a dynamic/sequential component to its Krumhansl-style hierarchy in its later sections, it nonetheless assumes that the basic space hierarchy is a necessary and fundamental component for tonal relatedness judgements, even if subject to some contextual modification through tension/release axes (pp.89–141).

potential heursitics:

> The intervallic rivalry model rests on three related hypotheses: (a) that listeners assume the first pitch of a sequence is the tonal centre until a better candidate arrives (the *primacy* hypothesis); (b) that listeners rely upon rare intervals more than common intervals in deriving a sense of tonal centre, as these provide more reliable key information by unambiguously correlating with a single diatonic set; and (c) that listeners are more accurate in determining key when a rare interval appears in a temporal order implying goal-oriented harmonic motion of a type common in tonal music. [Emphasis in original]

In relation to its potential applicability to microtonality, this theory makes no specific mention of this type of musical construction, either in corroboration or negation, but does offer a particularly dynamic potential model of musical hierarchy as an emergent form from heuristic listening 'rules' and suggests that listener expectations are less subject to a rigid and singular hiearchical schema (which can only be of benefit in the deployment of more unfamiliar materials). In addition, the focus on localised musical structures raises the issue of whether a model based on a relatively simple structure or set of heuristics can explain the parsing of musical structures in cognition. If, as Cross noted above, this is a significant bottom–up contributing factor to hierarchy/salience judgements based on principles related to the parsing of environmental auditory materials—Bregman's (1990) principles of *auditory scene analysis*—then some musical experience may be best treated through the application of such a model of heuristics rather than a fixed hierarchical model. In effect, for some configurations of materials, relatively simple rule–based perceptual processes relating to ecological organisational principles may have a more signficant bearing on musical experience than a more ornate top–down cognitive models.

6.3.4 Parncutt's (1989) Gibsonian/Ecological Theory of Harmony and its Microtonal Potential

A more extensively bottom–up explanation of tonal relations is also evident in Parncutt's (1989) psychophysically–based theory of harmony, which is itself elaborated on Terhardt's harmonic series template model for musical consonance (discussed earlier). Sethares (2004, p.86) notes that Parncutt's theory is 'a step in [the…] direction' of a theory of perceptual fusion's (i.e. Gestalt–style grouping) role in consonance and harmony; as discussed in chapter four, Tenney (1983, p.15) has presented the idea that perceptual grouping/segregation may provide a broad–based consonance/dissonance concept (CDC) which is usefully applicable to contemporary music.

More fundamentally, as Lerdahl (2001, p.86) notes, Parncutt's theory provides an example of a model for harmony which does not require a sophisticated cognitive model of tonal relations to explain the hierarchical salience of different note combinations. This model is effectively a Gibsonican/ecological[203] one, as Parncutt (1989, p.89) himself notes, requiring no extensive mediating structures other than those of the source 'object' and its salient perceptual attributes which give rise to structured perception. Lerdahl further notes similarities in the predictions of his own model and Parncutt's, suggesting that Parncutt's psychophysically–based approach does not necessarily

---

[203] See section 1.3.4 for a preliminary explanation.

invalidate his own pitch–space model, even though Lerdahl's is theorised as a cognitive rather than a more bottom–up or ecological model. Nonetheless, as discussed above, the structural features of the Lerdahl cone bear a strong resemblance to structural features of the harmonic series itself, suggesting that an ecological 'structure in the stimulus' model might be valid in this case. Lerdahl himself, however, prefers to view such a psychophysically–based ecological model as a foundational but partial model of tonal relations[204] (Lerdahl, 2001, p.86), which is consistent with his discussion of more elaborate functional cases based on tension/release axes. However, this argument could perhaps equally apply to a cognitive elaboration on a more ecologically–based structure of hierarchical relationships. Certainly, on the basis of the distinct similarities between the Lerdahl cone and the structure of the harmonic series itself, the question could be asked whether the perception of such relationships requires a more extensive cognitive intervention than a dimensional reduction due to octave equivalence and a template–based familiarity with the harmonic series structure.

Parncutt's model is based on Western common practice music, and so only encompasses only the 12TET chromatic divisions of the scale (Parncutt, 1989, p.79) and therefore does not directly offer an explanation for microtonal music cognition.[205] However, as it is broadly related to a harmonic series template, it may provide some insight into microtonally–relevant caes. The theory takes as its basis a model of *virtual pitch*–style mechanism for the parsing of chords[206] by Terhardt et al. (1982, cited in

---

[204] Lerdahl also notes here that Parncutt himself steps beyond what is strictly considered psychoacoustics.
[205] In addition, it is further based on Western common practice music's prioritisation of tonal consonance as a generally desirable sensory/structural attribute, in addition to examining cases which are articulated through harmonic rather than inharmonic spectra (Parncutt, 1989, p.80).
[206] Denoted as *algorithm for the extraction of pitch and pitch-salience from complex tone signals* (Parncutt, 1989, p.80).

Parncutt, 1989, p.80). Parncutt here focusses on its applicability to fixed pitch–categories (rather than examining the smaller pitch–shift cases which are applieed in the original model which is more concerned with this lower-level detail). The primary focus is on the salience of individual pitches within a complex, or *tone–salience*, which is expressed as a probability of 'noticing' (p.80) this tone in such a situation. This is based on the modelling of generalised harmonic timbres (or pure tones) with the computation of masking factors (*ibid.*, pp.85–88) and the converse *audibility* of individual components which are compared in structure to a *harmonic (series) template* (*ibid.,* p.89) to provide virtual pitch estimation through comparison with a harmonic template (which is alternately tested at different pitch-category positions/semitone steps). The model (see figure 56, next page) weights higher harmonics as less significant contributors to the virtual pitch percept (*ibid.,* pp.90,92). This is taken as comprising a ten-harmonic maximum for the sake of simplicity and to reflect reduced audibility/salience for components beyond this limit; however it is remarked upon here by Parncutt as possesing a favourable attribute with respect to removing the (microtonal) eleventh harmonic.

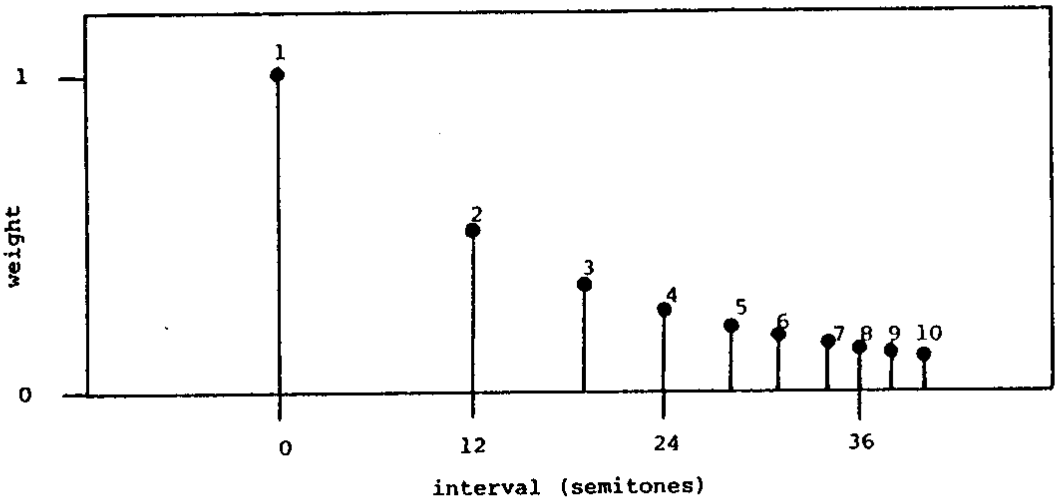


Figure 56: Weigthing of the first ten harmonic intervals (spatially graphed in relation to 12TET interval approximations), from Parncutt (1989, p.90)

As noted above, the salience of individual pitches within a complex is an important factor of Parncutt's model; for the case of an individual complex tone, Parncutt (*ibid.,* p.90) applies a relatively low salience factor for individual harmonic components (such that they do not 'compete' with the salience of the overall pitch percept for a complex tone in its entirety; i.e. they prioritise so–called *synthetic* over *analytical* listening conditions). However, it is notable here that strongly analytical listening cases can arise in microtonal music, as seen in the examples discussed in chapter four. As such, although Parncutt's model does not directly account for microtonal pitch categories, a core aspect of its working assumptions may be modified somewhat in microtonal cases, resulting in conditions of pitch–salience for harmonic components from beyond the first ten (which could conceivably contribute to a microtonally–expanded version of the

Parncutt model which applies to higher harmonic series intervals).[207]

Parncutt goes on to apply his theory in the macrocosm; for groups of harmonically complex sources in chords (*ibid.,* pp.92–3). To model this, he uses a measure termed *multiplicity*, which comprises values for audibility/salience of individual frequency components (i.e. analytical versus synthetic/holistic listening cases) and audibility of grouped/unified harmonic complexes as clear or obscured single voices. Crucially, two different levels of holistic listening may be present—those which define pitch judgements for complex harmonic stimuli from a single source and those which define holistic (root) judgements for chords (hence, forming a basis for a theory of harmony). Furthermore, what Parncutt (*ibid.,* pp.94–6) terms *sequential pitch relationships* are modelled using a combination of *pitch–commonality* (for number of salient pitch components in common between two successive notes, contributing to a directional articulation within harmony) and *pitch–distance,* which encompasses traditional frequency distances for each salient component in a complex sound/chord (based on standard 12TET categorisation, but could be modified to take account of salient microtonal intervals, as disussed above). Thus, Parncutt's theory is based on pattern–matching for harmonic and sequential relationships, with the harmonic relationships giving rise to virtual–pitch–style tonal judgements, providing the value *tonalness* (*ibid.,* pp.139–142) which is the how ambiguous/unambiguous (a value of 1.0 being particularly unambiguous) the model's tonal judgement for a chord/complex is. This tonalness is the essence of Parncutt's model of consonance (i.e. consonance is equated

---

[207] The harmonic weightings for template–matching in such cases may not be reduced as in figure 56; rather, if these intervals are particularly salient, they may be accorded weightings closer to those of the lower harmonics in the figure.

with simplicity/lack of ambiguity for the overall tonal judgement).

In this regard, higher microtonal intervals could work against the model, being less likely to provide high tonalness values if used in isolation, as can be seen in some of Parncutt's examples (*ibid.,* pp.143–144). However, this very ambiguity could produce a strongly contrasting axis of consonance/dissonance (simplicity/complexity). Thus, microtonal intervals could be seen as desirable in creative cases (if perceptually salient) as they could significantly reduce unambiguous tonalness. This provides a potential explanation of the broadly drone–based preferences of much microtonal music based on higher harmonic series intervals, such as Tenney's *Spectral CANON for CONLON Nancarrow* (Tenney, 1974) and the work of La Monte Young, discussed in chapter four, but also including the early (harmonic series) guitar symphonies of Glenn Branca such as Symphony No. 3 (Branca, 1983, movt 1, 0'45–2'58) [208]. The familiar template of a harmonic series is 'destructively' tested by adding salient upper harmonic intervals which provide an alternative pole of 'ambiguity' at the opposite end of a perceptual scale (in terms of Parncutt's tonalness/ambiguity, but also in terms of 'raw' pitch–height) to the grounding drone. Such an aesthetic could be seen as basing its harmony on a coexistence between near/consonant and distant/dissonant intervals, in terms of the perception of the composite sonority, with a certain degree of ambiguity being valued if other factors contribute to coherence. In this regard, adherence to relatively strict harmonic series tunings for smaller microtonal intervals in an upper register, reinforced by a tonic drone, could be expected to make this effect more robust for such 'distant'

---

[208] This symphony deploys the first 128 intervals of the harmonic series and features an interplay between ambiguous and clear tonal implications through the deployment of low drones for clear tonal statements after initial presentations based predominantly on high–register harmonic intervals from the more distant end of the 128–harmonic gamut.

intervals than might otherwise be the case.

Therefore, Parncutt's theory, in its reprising and development of Terhardt's theory of psychoacoustically–based harmony, reminds us that, under certain sensory conditions, the process of grouping for harmonically-related components may be robust enough to take advantage of higher harmonics as cues for grouping into a largely unified harmonic timbral mass (with associated pattern–based pitch perception) which nonetheless contains salient individual frequency components. If certain conditions are met, the cognition of music may prioritise sensory–based judgements over more complex cognition related to functional connections. In musics which are, in effect, 'novel sensory environments' (i.e. in which musical stimuli take forms which are designed to take advantage of such bottom-up parsing), it seems only logical that the auditory system would prioritise such basic sensory parsing. The drone–structure harmonic series music discussed above provides an example of a form of music which appears to be trying to exploit such mechanisms (and this applies more generally to any microtonal music which applies extended durations, resulting in sensory rather than functional attributes being more likely to dominante). Even if Parncutt's theory were merely to provide a mechanism which *contributes* to the formation of Krumhansl/Lerdahl–style structures of tonal hierarchy judgements, as discussed above these structures bear a striking resemblance to the root ecological form of the harmonic series (i.e., they could also be explained as descriptive formal structures rather than explicit cognitive structures). In addition, even if the Krumhansl/Lerdahl structures are cognitive models which are emergent forms created from exposure to the Parncutt mechanism, musical cases which are structured to highlight sensory attributes (through the use of just intonation tunings with extended durations/drone–based structures) could plausibly ‘short–circuit’ the top–down cognitive model in favour of the bottom–up perceptual mechanism.

The difference between such cases could be described as the difference between the stronger timbral–style grouping of sustained intervals articulating harmonic intervals and the slightly weaker chordal–style grouping of intervals which only roughly approximate harmonic intervals (and are, perhaps, subject to shorter articulations). The former is clearly the result of a perceptual process. The latter may be the result of the application of a cognitive/formal model (which may be roughly based on the basic perceptual grouping case). However, the fact that a psychoacoustically–based model which explains many aspects of harmony could plausibly render the cognitive model explanation somewhat unnecessary in a broad range of musical cases, particularly those which prioritise sensory over functional attributes. If this case is true for even some musical cases, it suggests that bottom-up sensory judgements may contribute significantly to some microtonal cases and may enhance the salience of these intervals if certain conditions are met. It further suggests that, based on such principles of ecological structuring, microtonal intervals may be more perceptually relevant in the context of certain totalities (i.e. overall tonalness judgements for chords) than as individual intervals which are remembered accurately themselves.

In this context, it is the environmental structure which imposes restrictions based on certain specifications (sustained tones using integer multiples, within reasonable tolerance values based on periodicity dissonance effects) if perceptual experience is to be coherent in the domain of harmonic relations. The configuration of microtonal intervals in these cases requires precision rather than arbitrariness due to ecological and perceptual constraints rather than cognitive ones. In such cases, a musical consonance–dissonance model based on an exploitation of tonalness (in the sense of carefully–specified ambiguity) could validate the use of microtonal intervals related to harmonic intervals in holistic rather than individual contexts, thus alleviating concerns related to limited STM capacity for the parsing of microtonal materials in such cases. Holistic microtonal cases may be perceptually articulated by a consonance–dissonance model which is based on an exploitation of tonalness as the prime factor structuring perceptual experience rather than more extensive higher–order cognitively–based parsing/memorisation for individual microtonal intervals.

6.4 Embodied and Multi-modal Models of Tonal Cognition

6.4.1 Embodied and Ecological Models in Cognition

Another approach to tonal cognition which benefits from a potentially low cognitive load (i.e. does not require significantly complex structures at the top–down cognitive level) is that suggested by *embodied cognition* (Lakoff and Johnson, 1980, 1999; Varela et al.,1991; Clark, 2008; Rowlands, 2010; Shapiro, 2011); see preliminary discussions in the introduction (section 1.3.4). To briefly recapitulate, this current within the cognitive sciences (and philosophy) situates cognition as a negotiation between an active agent in the environment and that environment's interaction possibilities and is thus influeced by Gibson's *ecological perception* (Gibson, 1966; 1979), also known as *direct perception* (due to its theorised lack of mediating cognitive models in the process of perception). However, exponents of embodied cognition differ from classical Gibsonian ecological perception in that they posit cognition as structured and *situated*—

an alternative term used instead of *embodied* in some accounts, e.g. Clark (2008)—by the nexus of environmental and biological factors through which an organism responds to its situation (rather than perception being *direct* and largely bottom-up, thus being cognitively unmediated, as in Gibson).

In short, with embodied cognition, the act of cognition still occurs, but is closer to the structure of the environment/body interacting nexus than the structures theorised in classical cognitivist account might be. As discussed above, Parncutt's model is viewed as a Gibsonian ecological theory of harmonic relations which is a possible parsimonious alternative to more ornate top–down pitch hierarchy models (such as those of Krumhansl and Lerdahl). However, embodied cognition offers a perspective which might produce a more plausible simplification which could explain the structure of more apparently complex cognitive through simpler, environmentally–grounded models. Nonetheless, these processes are seen as tempered by a parsimoniuous simplicity of adherence to the structure of the environment itself and its interaction possibilities; by what Shapiro (2011) terms *replacement*, whereby:

> An organism's body in interaction with its environment *replaces the need for representational processes* thought to have been at the core of cognition. Thus, cognition does not depend on algorithmic processes over symbolic representations. It can take place in systems that do not include representational states, and can be explained without appeal to computational processes or representational states.
>
> (*ibid.*, p.4) [italics mine]

This is the more extreme end of the embodied cognition argument and is based on

Gibsonian *direct perception*. However, the more plausible general principle is that an organism could gain a cognitive advantage (in terms of reducing cognitive load) by offsetting some (i.e. as many as supports reasonably accurate judgement) structural aspects of cognition to the environment itself, i.e. following it in a relatively unmediated way.

This impulse may, however, work alongside the more tempered process of (metaphorical and cross-domain) *conceptualisation*, whereby '[the] properties of an organism's body limit or constrain the concepts an organism can require' (*ibid.*). This approach—the essence of embodied cognition——seeks to explain cognition as 'grounded in sensory-motor experience […so that] abstract human ideas make use of precisely formulatable cognitive mechanisms such as conceptual metaphors that *import modes of reasoning from sensory-motor experience*' (Lakoff and Núñez, 2000, p.xii) [italics mine].

Based on this ecological/embodied perspective, the nature of musical—and, indeed, a wide range of formal—structuring in mental processes is currently the subject of debate within the cognitive sciences. Embodied cognition offers a challenge to non–embodied/non–ecological models of representation in the context of their explicating power for modelling human perceptual and cognitive experience: Lakoff and Johnson (1999, pp.99–102) discuss challenges to propostional logic which does not reference embodied models. Indeed, even the abstract formal structures of mathematics have been the subject of investigations from this perspective (Lakoff and Núñez, 2000). As these authors assert their central thesis:

> Human mathematics, the only kind of mathematics that human beings know […] arises from the nature of our brains and our embodied experience.
>
> (Lakoff and Núñez, 2000, p.xvi)

The structures derived from embodied experience which Lakoff and Núñez posit as the metaphorical bases which are 'imported' into mathematical reasoning are termed *image schemas*[209] (Lakoff 1987; Johnson, 1987; Lakoff and Johnson 1999, p.77). Such schemas are the abstracted representation of various movements/interaction gestures which are typical of our environment and are applied as *cross–domain mappings* (or *metaphorical mappings*) to a range of cognitive processes (*ibid.,* pp.57–8). Lakoff and Johnson further note that:

> Our brains are structured so as to project activation patterns from sensorimotor areas to higher cortical areas […becoming] *primary metaphors* […] Reason is embodied in that our fundamental forms of inference arise from sensorimotor and other body-based forms of inference.
>
> (*ibid.*, p.77) [italics in original]

Thus, a bottom–up mapping causes certain basic environmental/body–based abstracted structures to be applied to more complex cognitive tasks, such as the cognition of musical structures, e.g. (Zbikowski, 2010, pp.68–70; Brower, 2008, pp.9–45; Snyder, 2001, pp.95–117).

The basic image schemas are, as Johnson (2008, p.141) notes, 'a crucial part of our *nonrepresentational* coupling with the world' [italics mine], i.e. are the stuff of

---

[209] This more contemporary version of the plural of 'schema' is preferred over 'schemata' in the majority of the literature and so will be used here in this context.

Gibsonian unmediated perception. However, this marks a crucial dividing line between embodied models of cognition and the basic Gibsonian case, with the cross–domain mapping of these basic schemas to other domains, extending into more abstract realms of reasoning and making structural 'decisions' about perception (*ibid.*). Johnson (2008, p.21) summarises and categorises typical image schemas as follows (figure 57):

(1) UP–DOWN (Verticality)

(2) INTO/OUT OF (Container) [210]

(3) TOWARD/AWAY FROM (Centre/Periphery or Scalar Distance)[211]

(4) STRAIGHT/CURVED (Scalar or Cyclical Distance)

(5) SOURCE–PATH–GOAL[212]

Figure 57: Summary of some of the main embodied image schema types, adapted after Johnson (2008, pp.21,141).

Not only do these image schemas describe spatial relations and interactions; they can also be viewed as describing (indeed, being grounded in) the associated force/effort to carry out these movements (*ibid.*, p.24). For example, the vertical schema implies that the force of gravity is being resisted (Brower, 2008, p.10). It is also important to stress that this perspective does not anticipate the use of these schemas in isolation when applied to either interactions (see footnote 199) or abstract reasoning. As Lakoff and Johnson note:

> *Conceptual systems are pluralistic, not monolithic.* Typically, abstract concepts are defined by multiple conceptual metaphors, which are often inconsistent with

---

[210] cf. (Brower, 2008, p.10).
[211] cf. (*ibid.*)
[212] Defining the preferred outcome of a schema-based activity; 'parses' a schema to be interacted with, such as a container schema ('the egg went into the saucepan').

each other.

(Lakoff and Johnson, 1999*,* p.78) [italics mine]

Thus, there is the potential to use image schemas for what may appear to be highly abstract reasoning, as Lakoff and Núñez (2000, pp.383–451) have discussed in relation to mathematics. In this regard, embodied cognition offers a potential model of musical experience which allows for the representation of relatively complex structures in a cognitively efficient manner and furthermore presents a less disjuncted model which eschews extreme polarities of bottom-up and top-down. In addition, the modularity of this approach reinforces the plausibility of a more adaptive model of musical parsing than is envisaged in the basic Krumahansl 'cone' hierarchy.

6.4.2 Embodied Cognitive Models of Musical Pitch

Brower (2008) provides a particularly valuable account of how these basic image schemas might be combined to apply to the cognitive structuring of musical pitch. The two primary schemas which are applied in this search for embodied models of pitch are the *vertical* and *cyclical/circular* schema (see figure 58, below, next page).

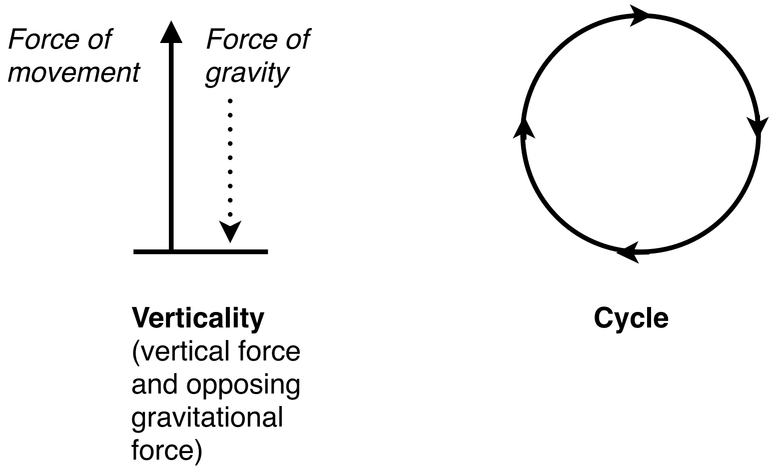


Figure 58: Two basic image schemas with potential applicability to pitch structures, after Brower (2008, p.10).

The potential for using these two schemas together to define an embodied version of the pitch–height/pitch–chroma division of musical pitch should be clear. Brower's account follows this general basis (*ibid.* p.17), but focusses first (*ibid*., p.15) on the elaboration of vertical/hierarchical aspects of this potential model in the search for an embodied model for musical triads (see figure 59, below, next page).

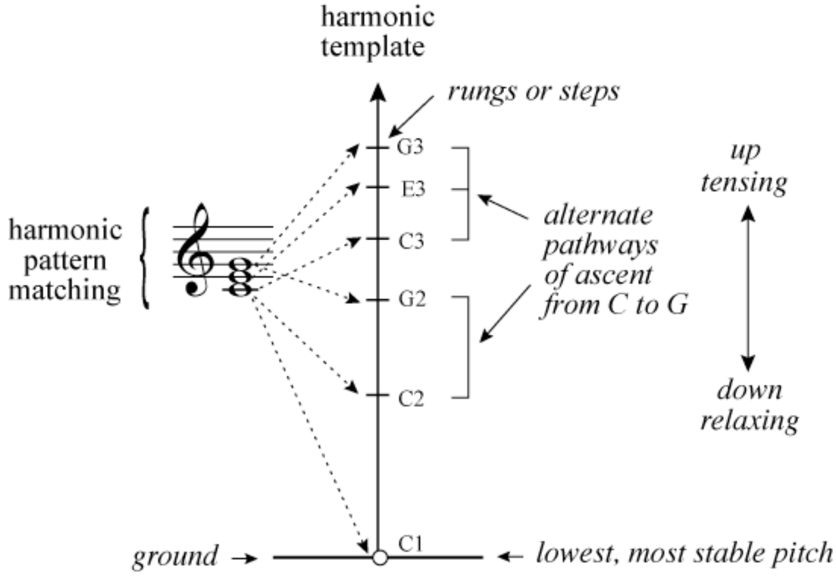


Figure 59: Brower's (2008, p.15) embodied model of triadic (and more general harmonic) hierarchy

At the base of this model is the Terhardt/Parncutt ecological theory of harmonic hierarchy as related to psychoacoustical factors (Terhardt, 1974; 1979; 1984; Parncutt, 1988; 1989, cited in Brower, 2008, p.15). Brower here seeks to find an alternative to the *Tonnetz* for the representation of tonal relations, noting that 'relative stability' is not made clear by this more traditional graphic representation (*ibid.*, p.14); a similar point to Lerdahl's (2001, p.45) critique of the *Tonnetz* as potential prototype for a psychological model. Similarly to our discussion of Parncutt's (1989) theory and its application to a microtonal consonance/dissonance concept, Brower focusses on a hierarchical harmonic template related to the harmonic series (only explicitly representing the first three harmonic pitch–chroma intervals, but making it clear that this hierarchy could continue upwards), referencing a vertical tension (upwards) and release (downwards) axis.

This model is therefore both embodied (in this sense), but also specifically ecological in its structure (as a subset of the embodiment/environment nexus), containing the structure of the harmonic series within it. In addition, as can be seen from the diagram above, this representation also encompasses ‘alternative pathways of harmonic motion’ (*ibid.,* p.16) through individual pitch-chroma relations such as fifths and thirds (and, although Brower does not explicitly state this, other ‘step-wise’ or functional relations —including microtonal harmonic intervals—could be encompassed by this model if the series were to be extended). However, as this representation remains one–dimensional (if perceptually non–linear in terms of the harmonic scale steps), the tension/release vertical axis is not fully true to perceptual experience which conforms to the octave-equivalence case. This is the basis on which Brower reprises the Shepard pitch-chroma/height ‘spiral’, whilst noting the cyclical and vertical image schemas implicitly embedded within it (see figure 60, below, next page).

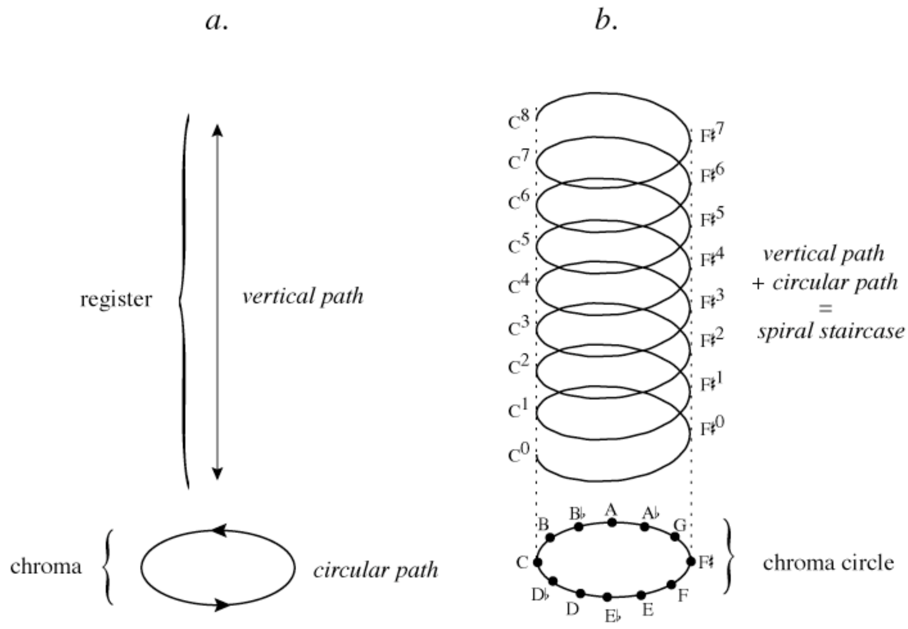


Figure 60: Brower's (2008, p.17) comparison of vertical and circular schemas with the Shepard 'spiral staircase' representation

6.4.3 Towards an Embodied Model of Tonal Cognition and Microtonality

At this point, our interests diverge from those of Brower, who is seeking an embodied model of triadic relations through re–imagining the *Tonnetz* based on a composite of image schema concepts (*ibid.*, pp.18–32). This type of representation is incompatible with the present project's direction for two reasons: (1) most importantly, it is limited to 12TET intervals[213]; and (2) it remains a representation of potential functional 'paths' which does not represent the perceived psychological magnitude of interval distances,

[213] This could be addressed by adding extra functional dimensions, but at the expense of any connection to relatively simple embodied schemas.

prioritising instead a representation of functional ‘steps’. Based on these factors, it is of more potential utility in depiciting dynamic modulatory/functional connections between intervallic nodes rather than depiciting a more basic case of a relatively fixed hierarchy with respect to a single tonal centre (but extended in the direction of intervallic expansion through microtonal subdivision).[214] However, following Brower’s earlier line of investigation regarding verticality metaphors and their connection with harmonic series intervals may provide a more fruitful avenue of exploration with regard to microtonality. Potential points of agreement between the Krumhansl/Lerdahl cognitive models on the one hand and the poential simplicity of ecological/direct perception based on the harmonic series might be found through the medium of embodied image schemas, which could suggest a more generally bottom–up theory of harmonic hierarchical relations which nonetheless provides a less extreme model than ecological *direct perception*. If the combination of image schemas can be used to account for the ‘spiral–staircase’ pitch–chroma/pitch–height model of Shepard, perhaps a combination can be found which provides a similar perspective on the Krumhansl/Lerdahl cones and their potential perceptual implications.

The circular path and verticality schemas provide two simple bases to construct an embodied version of a cone-based model similar to the Krumhansl/Lerdahl cones; the circles at each successive level become wider to reflect their distance from the cone’s origin. In addition, Brower has already provided us with a prior model of how the

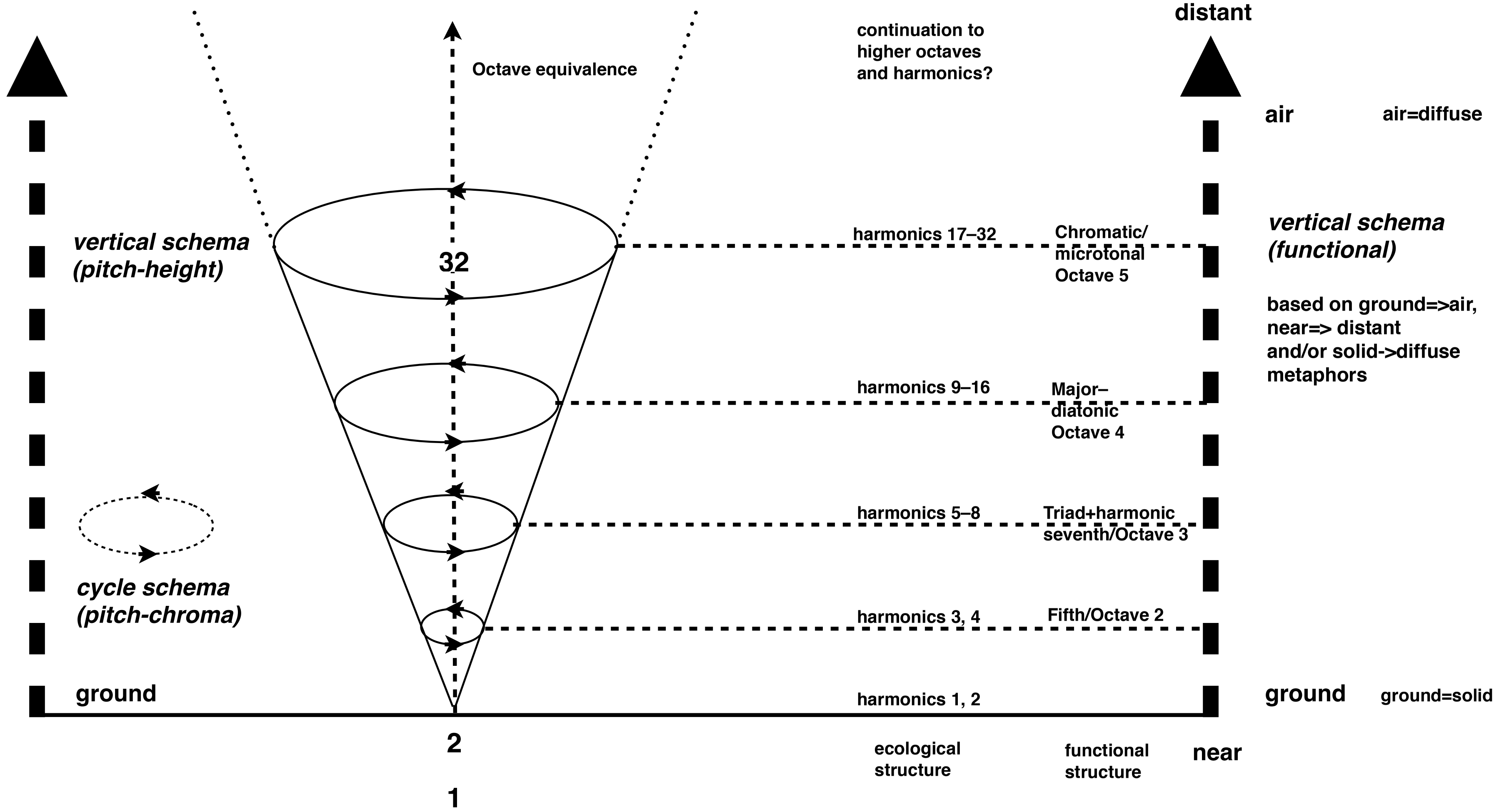
---

[214] In addition, in more general terms, it could be argued that the ‘embodied *Tonnetz*’, whilst constructed using components derived from image schema, has an overall structure which obscures this derivation. That said, there is nothing in the theories of embodied cognition proponents which expressly forbids this type of elaboration; however, based on the arguments above, for musical cases which highlight sensory rather than functional conditions, a less mediated model which is closer in structure to the source percept might be expected to be of greater utility in terms of reducing potential cognitive load.

ecological structure of the harmonic series might be applied to a verticality schema (see figure 59, above), although this does not encompass a structure to deal with octave equivalence. In this regard, my earlier elaboration of the Lerdahl cone with harmonic series intervals replacing 12TET pitch–classes (thus providing an explicitly microtonal extension, which Brower's figure avoids) may be adapted to explictly reflect a verticality schema which depicts the proximal relations due to octave equivalence. Figure 61 (below, following page) depicts a possible cognitive structure for musical pitch which is based on a combination of image schema with the ecological harmonic series structure. It combines a vertical image schema with related metaphorical interpretations of this schema—spatial (near/distant), substance-based (ground/air or solid/diffuse[215])—along with categorisation by functional role for different points on this axis (octave, triadic, diatonic, chromatic/microtonal). The solid–to–diffuse axis indicates that higher harmonics (and functional levels) may possess a degree of relative ambiguity in their relations to the 'ground'/root/tonal centre (which tallies with our earlier description of extended harmonic series microtonality—e.g. the work of Tenney and Branca—in the context of the Parncutt/Terhardt model).

Figure 61 (following page—full-page diagram): Integrating ecological, functional and embodied schemas based on verticality and circular path structures, integrating various veticality-related metaphors

[215] Cf. Talmy (2005, p.211).



Octave equivalence
continuation to higher octaves and harmonics?
distant
air
air=diffuse
vertical schema (pitch-height)
32
harmonics 17–32
Chromatic/ microtonal Octave 5
vertical schema (functional)
based on ground=>air, near=> distant and/or solid->diffuse metaphors
harmonics 9–16
Major–diatonic Octave 4
harmonics 5–8
Triad+harmonic seventh/Octave 3
cycle schema (pitch-chroma)
harmonics 3, 4
Fifth/Octave 2
ground
harmonics 1, 2
ground
ground=solid
2
ecological structure
functional structure
near
1

This representation provides us with a potential beginning for integrating bottom–up perceptual and more top–down cognitive structures based on embodied image schemas (which are themselves bottom-up in origin). Through this (more holistic) integration, it offers the potential to describe a model of perception which benefits from a less oppositional or exclusivist relationship between bottom–up and top–down conceptions of musical pitch. It combines the environmentally–derived schema of the harmonic series with structural delineation based on a relatively simple combination of two basic image schemas (cycle and vertical), enriched by a variety of metaphorical/cross–domain mappings on the vertical schema. In doing so, it provides a description of musical pitch–space which appears to tally with both the findings of psychological research for perceived hierarchies/distances between tones. Furthermore, its structural division also appears to tally with significant functional divisions in harmonically-based musical practice (octave, triadic, diatonic, chromatic/microtonal). Whilst it does not offer the same simplicity of representation for formal/functional dimensions which the *Tonnetz* and related lattice structures do, it benefits from representing pitch distances in the pitch-chroma domain by scalar/within–octave cycles (which conforms to more closely to perceptual experience) whilst maintaining a level–based functional distinction related to the structure of the harmonic series.

Although more musically experienced/particularly active listeners may (eventually) elaborate functional lattices as they search for generative structures within a particular piece, the psychological evidence does not currently explictly support such a cognitive structure as generally applicable to musical listening. Thus, based on this proposed model, the cognitive structuring of music may be based upon the elaboration of embodied image schemas upon the ecological schema of the harmonic series, resulting in a sophisticated but relatively compact metaphorically-based model of pitch–chroma and pitch–height relations whose structural divisions may be further elaborated to reflect emergent functional relationships, based on sensory conditions which are salient enough to significantly affect the cognition of microtonal pitch materials (which is consistent with earlier discussions).

6.4.4 Towards an Embodied and Multimodal Model of Tonal Cognition and Microtonality

This model is therefore less extreme than a solely ecological 'direct perception' model (in that it posits a role for cognitively–based schema) and has a number of benefits for our present purposes. It accounts for the 'metaphorical' associations of pitch–height and tonalness 'ambiguity'. It suggests a functional division for tonal materials which includes microtonal ones at its post–diatonic level. Indeed, in overall terms, it maintains a tonal structure/functional division which is a basic elaboration on the perceptual structure of the harmonic series, offering the potential to reconfigure tonal cognition as being a combination of top–down and bottom–up effects, with a suggestion that cetrtain bottom-up sensory conditions may greatly affect the nature of tonal cognition. The contribution of bottom–up factors to interval definition (i.e. the basic perceptual salience of certain tuning conditions) is suggested as being of potential significance for certain musical conditions (sustained harmonic tones). However, this model could also be extended to allow for further functional delineation: the influencing of interval perception by top–down learned categories (see figure 62, below, next page). In this diagram, microtonal materials are delineated from chromatic materials in a separate functional/hierarchical layer, based on the findings of Jordan (1987), although, as discussed above, such delineation may be heavily dependent on the conditions of presentation.

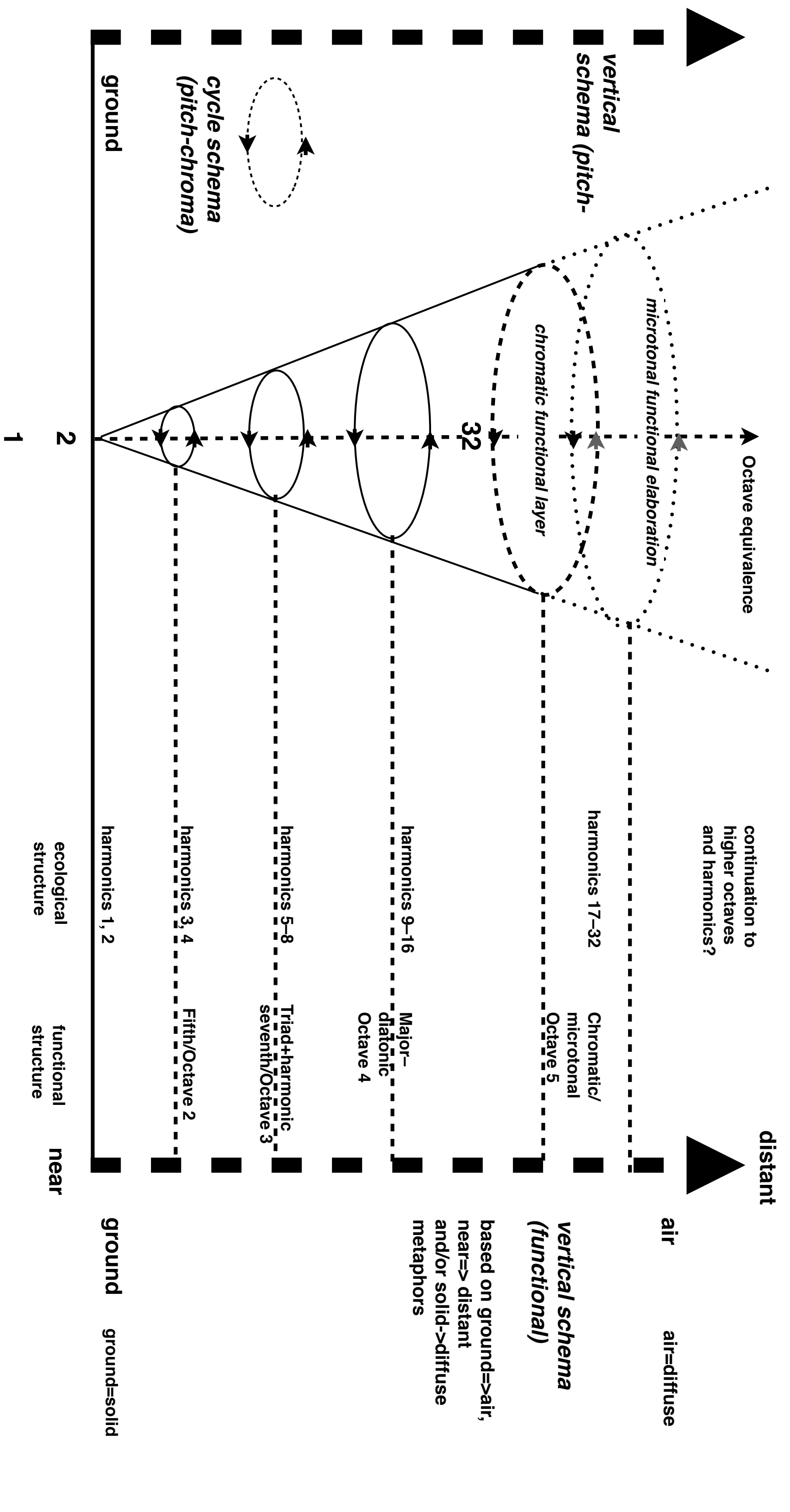


Figure 62 (above, previous page): Addition of extra functional layer (through top–down categorisation processes) to the ecologically–based tonal hierarchy model, based on the findings of Jordan (1987).

A representation which consolidates the bottom–up and top–down processes which are theorised as being at play is provided in figure 63 (below, next page). This diagram depicts a two–way interplay between these two factors/strategies in perception whose relative strengths will depend on the nature of the musical materials; extended–duration presentation of harmonic/just–intonation–based intervals may cause bottom–up factors to predominate…briefer durations or other conditions which do not foreground sensory conditions of intervals as strongly may cause top–down definitions of broad interval categories to dominate. As an example of these types of interrelations, the formal (and sensory) connection between 3/2 and 9/8 is shown here (with further modulation beyond this structure from 9/8 to 81/64 also indicated).

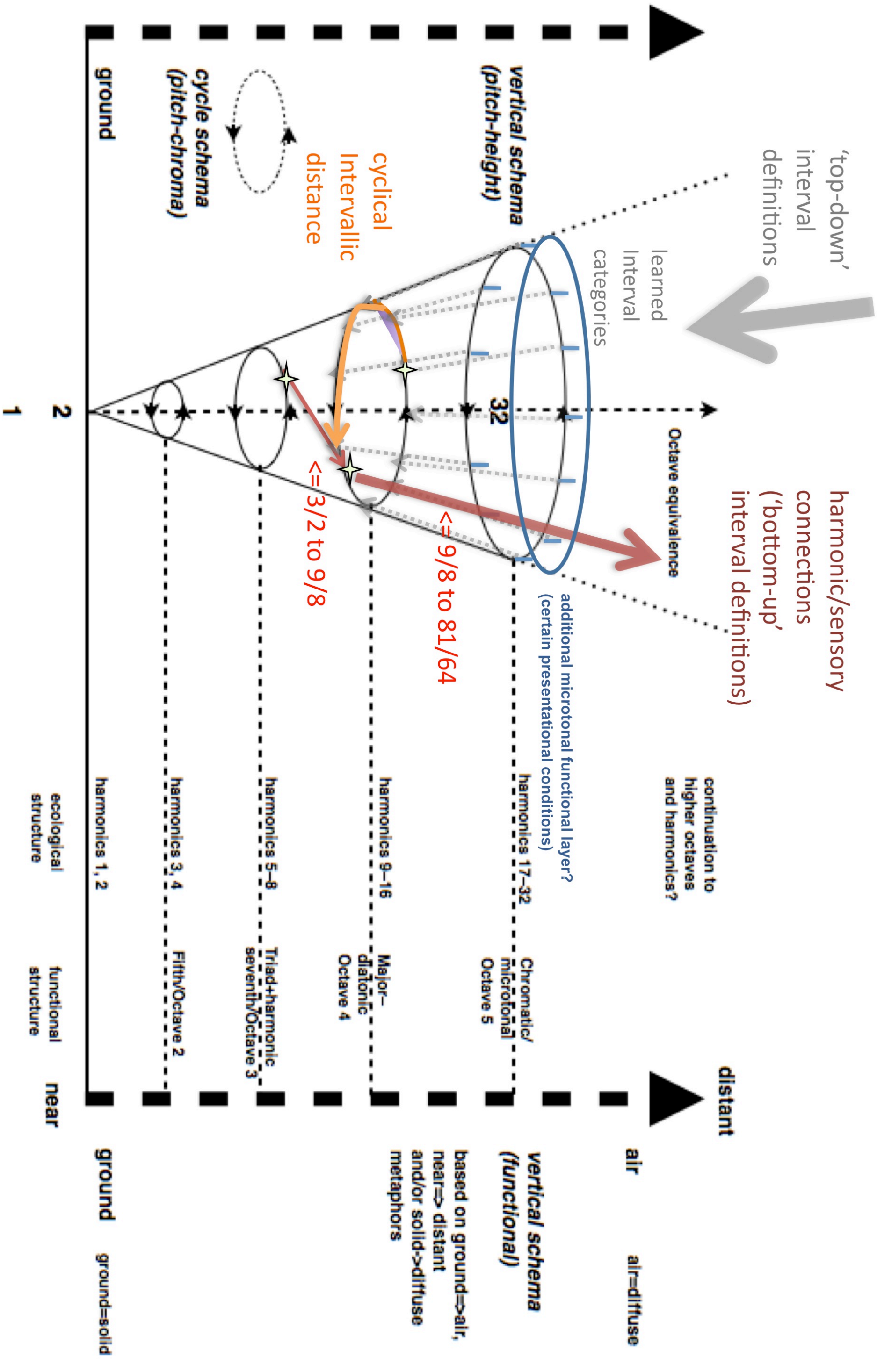


Figure 63: Harmonic relationships depicted via position in pitch-chroma cycle and procedurally-based harmonic/sensory connections (bottom-up structuring) in addition to influence by top-down learned interval definitions

In addition, this model accurately encompasses cyclical scalar distances for interval relationships within the pitch–chroma cycle (with functional *differences*—as opposed to *distances*—depicted by between–level connections). The functional implications of the model are enlivened by the overall vertical metaphors of solid/grounded to diffuse/ambiguous, which is represented by the increasing size of the chroma-circles (making new intervals at each successive level more 'distant' than the intervals from the last level).

The relationships between the levels in this model are such that when, for example, a harmonic of a harmonic is defined (e.g. a ninth harmonic of a ninth harmonic, forming the Pythagorean major third), it is constrained by a learned interval categorisation until a particularly salient sensory condition is reached (e.g. through accurate tuning in interval combinations), at which time the perceptual judgement may overtake the larger-scale learned interval category judgement and substitute a microtonal nuance/textural variation as a new category. Whilst such an interval definition may be relatively temporary, it is nonetheless the subject of a perceptually salient structure and so is likely to be stored in memory (perhaps as a quasi–textural percept). In addition, the generalised contextual/adaptive basis of perception may mean that a preponderance of microtonal pitch variations within a very small range may result in the adaptation that small changes in pitch become more salient as finer degrees of discrimination/sensitivity are facilitated through these conditions (which could be accounted for through the model of CP proposed by Pastore, and Scharf's theory of *perceptual attention bands*, as discussed in chapter five and the previous section).

On these bases, it is the contention of the present thesis that the cognitive salience of microtonal music is largely dependent on bottom–up perceptual conditions. It is therefore a form of musical expression whose audible structuring may be quite sensitive to presentational conditions. As such, the present model allows for pitch materials to be configured in two different cognitive–perceptual directions: learned/cognitive-structural top–down and perceptual/sensory bottom–up processes/strategies. The top–down direction accounts for the application of learned interval categories to a pitch stimulus, assigning it on the basis of its conformity to these prototypes. This form of cognition prioritises the reduction of a wide variety of pitch–frequency gradations into a relatively small number of learned discrete categories or scale steps (which are themselves emergent based upon the sensory attributes of various pitch/frequency configurations). It may be dominant in unaccompanied melodic contexts or, more broadly, whenever melody highlighting functional relations rather than composite sonority is more obvious. Larger leaps in pitch may be perceptually quantised to these broader categories on this basis. However, more subtle within-category discrimination will be salient for certain musical conditions (for, as noted in the last chapter, CP for pitch is not based on absolute re–coding).

This finer degree of discrimination is salient on the basis of bottom–up perceptual processes and conditions, as opposed to the larger–scale top–down categorisation. In addition, the context of embodied image schemas provides a fruitful cross–domain mapping for functional divisions based on the harmonic series structure. On this basis, microtonal materials may be broadly rather than individually parsed to judge their contribution to clear or ambiguous tonal relations. As such, even microtonal materials which are not in-and-of-themselves structurally salient may nonetheless be so in the context of a holistic, ecologically–grounded multimodal model—cf. Snyder's (2001, p.95) discussion of schemas as supra–categories for 'regularities in the environment—which utilises a variety of co-existent strategies to make sense of structured pitch and resultant texture. The present model therefore has the advantage of providing a framework within which individual categorised materials can coexist with more broadly–based schematic judgements, accommodating structural reconfigurations on the basis of whether top–down or bottom–up factors predominante.

In this context, the present model accounts for both larger–scale discrete categorisation and smaller–scale microtonal nuance/textural discrimination, which may contribute to more defined categorisation judgements in musical contexts where microtonal structural aspects are highlighted (in sonority or in sequential presentations which focusses on microtonal variations within a relatively small pitch range). With this in mind, the putative model discussed above may suggest that creative strategies for microtonal deployment should also bear perceptual cues in mind in terms of both sonority (timbre of sound source and tuning details) and sequential presentation (microtonal materials treated on the basis of distinction/discrimination within broad interval categories rather than as significant in larger melodic leaps). Some of the creative strategies which may give rise to distinctive microtonal experience will be explored in the next chapter, which treats the composition component of the present research project.

6.5 Conclusion: The Psychology of Pitch Environments

This chapter has explored how more holistic treatment of pitch materials (in the context of spatial conceptions of pitch) may account for the cognitive salience of microtonal music. In contrast to an atomistic account based on individual intervals (which runs the risk of easily exceeding the Miller limit for microtonal cases unless another sonic dimension is cross–referenced), hierarchical relations based on the modelling of difference/similarity between tonal materials may play a significant role in accounting for cognitive structural capabilities with regard to microtonal materials. Broad agreement is found between the cognitive–structural theories of Krumhansl (1979; 1990) and Lerdahl (2001), which suggest that tonal relations may be reliably described by cone–based hierarchical representations encompassing octave, triadic, diatonic and chromatic functions, which on first examination seems to exclude microtonality. However, it is proposed that Krumhansl's theory may be further extended into the microtonal domain through the adaptation of the Krumahnsl (1979) cone by integrating findings from Jordan (1987) for quartertone intervals. Furthermore, it may be possible to account for the experimentally–observed regularities in tonal experience by other methods which are based on a more parsimonious representation—e.g. the heuristically–based cognitive account of Butler (1989)—or even one which eschews representation in favour of replacing an extensive top-down cognitive model with a simpler bottom–up process, such as the psychoacoustically–based account of Parncutt (1989). The latter account benefits from drawing a parallel between the bottom-up process of virtual pitch detection and root–detection processes for harmony. Usefully, this type of account appears to be amenable for explaining holisitic microtonal relatedness judgements and the weighting of the contribution of individual pitches to its *tonalness* axis (from clarity to ambiguity) suggests a holistic role for microtonal materials (when salient), even if aspects of their individual structuring (i.e. scale structure) are less directly amenable to structural parsing and memorisation.

However, purely Gibsonian ecological perception is undoubtedly an extreme position in its removal of cognitive representation in the modelling of perception. As such, a model which integrates a relevant ecological structure (in this case, the harmonic series) with some degree of top–down cognitive structuring is more likely to be amenable to describing more active perceptual engagement (and memorisation) of complex materials. This is potentially important, as top–down structuring may be more typical of musical listening conditions (for forms of music which have a clearly–established functional base), especially if musical 'distance' judgements are subject to contextual change, as Shepard (1982, p.306) has observed. That Lerdahl's (2001) analysis and adaptation of Krumhansl's (1979) cone suggests that such functional divisions may be embedded in the representation of the cone (even if, as Lerdahl discusses, they may originate due to differing psychoacoustic attributes of some intervals in comparison with others) offers us a hint that some process of abstracted representation may be relevant in this case (and may therefore contribute to the creation of adaptive abstracted models). Such abstracted representations may not represent a complete break from the bottom-up ecological/perceptual structures. However, in contrast to the arguments of Shepard (1982, p.310), who contended that once transduction had taken place, psychophysical processes were largely extraneous to cognitive concerns, this account has argued that such an extreme division is less likely to be helpful for circumstances such as those typically found in contemporary musical practice.[216] Indeed, the presence of explanations for categorical perception based on psychophysical effects (Pastore, 1987) and the findings of attentional priming effects within narrow frequency ranges (Scharf et al., 1987), in addition to the findings of Ferrer-Flores (2007) with regard to interval learning, and the efficacy of Parncutt's (1989) psychoacoustically–based model of harmony, suggests that that bottom–up processes are, indeed, relevant in many cases related to the cognition of musical intervals.

Given the obvious advantages which the addition of top–down models possess for music cognition[217], the search for a more broadly–based model which might more closely integrate these two cognitive–perceptual strategies would appear to be a useful activity. In this regard, Brower (2008) offers a pertinent suggestion relating to the potential cognitive modelling of pitch using embodied image schemas (which are themselves derived from bottom-up–sensorimotor patterns). This type of cognitive modelling of tonal relationships would therefore facilitate the incorporation of bottom–up components alongside top–down schematic structures based on cross–domain metaphorical mappings derived from more general embodied experience. Such a model would provide the advantage of a less abrupt transition between bottom-up and top-down processes, which might suggest a more fluid interplay between the two. This form of model is also likely to be more broadly applicable, explaining both primarily sensory–based cases relating to tuning and sonority, including those of microtonal

[216] Which may frequently foreground textural/sensory attributes to a greater degree than in common practice music. In this regard, Shepard's appeal to the conventional wisdom of music theory bears some of the hallmarks of a circular self-fulfilling prophecy constrained by his familiarity with a particular musical style and culture (common practice Western music).
[217] Providing ready–made generalised schema which may contribute to the development of more genre–specific and composition-specific structures upon repeated exposure.

salience, and learned categorical relationships. It is a model which could plausibly be regarded as tracing a process whereby salient perceptual phenomena and emergent functional categorisation processes come together to produce a cognitive model and process whose form maps a relatively complex set of relationships but whose component parts are closely related to frequently–encountered or relatively simple environmental structures. Indeed, the use of a model based on embodied and ecological schemas is also broadly consistent with the ecological schema–based component of Bregman's (1990, pp.395–453) theory of more general organisational principles employed within auditory perception processes.

Furthermore, this theory is broadly consistent with those of Johnston (who proposed just–intonation–based microtonality for its provision of an extra degree of formal and sensory detail within *pitch–category regions*) and Tenney (who proposed a tolerance-limited—i.e. categorically–limited—ratio-based functional model and an ecological model as potential contributors to microtonal cognitive salience). Indeed, the present theory offers a particular advantage in relation to the model of microtonality favoured in Tenney's *Critical Band* (Tenney, 1998b): it offers a point of intergration between this piece's ecological structure and the cognitively–based structures which Tenney assumes in his other theorising. In addition, the perspectives drawn from embodied image schemas which are embedded within this theory provide a general point of compatibility with the embodied exploration of Young's installation works. This aspect of the ecological/embodied framework which underpins the present theory is also beneficial in terms of its potential compatibility with other musical practices: for example, the gestural/textural structures of various styles and approaches such as various forms of experimental, electroacoustic and post–digital musics. Its embodied and ecological structures can accommodate a wide range of sonic information, whilst still maintaining a relatively straightforward depiction of formal properties (which can be elaborated further by theories which are less concerned with relatively immediate cognitive experience). In doing so, it elucidates a role for microtonal materials through their bottom-up intervention within the model's ecological structure, whilst also allowing for larger top-down categories to predominante in certain musical configurations.

6.6 Chapter Summary

This chapter has investigated factors in the structured perception of pitch materials from a more holistic perspective than the atomistic focus in the previous chapter. The potential importance of contextually–derived hierarchical groupings is discussed with reference to a number of potential explanations. Cognitive–structural theories which are used to explain common practice Western music—Krumhansl (1979; 1990) and Lerdahl (2001)—are investigated with reference to their potential extension for microtonal materials, with the findings of Jordan (1987) with respect to the hierarchical salience of quartertones being cited as significant in this regard. In addition, the similarity between the proposed cognitive–functional models of Krumhansl (1979; 1990) and Lerdahl (2001) and the ecological structure of the harmonic series is treated. A bottom–up model of tonal relations (Parncutt, 1989) is also discussed, lending weight to the proposal that ecologically–based processes and structures could contribute to the perception of complex tonal materials. An integrated bottom–up/top–down theory is proposed based on embodied cognition, whereby the ecological structures described above are elaborated via the addition of sensorimotor–based image schemas from which functional roles are derived. To summarise such a process, salient perceptual phenomena and emergent functional categorisation processes come together to produce a cognitive model and process whose form maps a relatively complex set of relationships whilst minimising cognitive load due to the derivation of its parsing/organisation process from familiar environmental models and activities. In short, the perceptual distinctiveness of various microtonal cases based on coherent just intonation renderings of intervals could provide a basis for their cognitive–functional organisation in a manner which efficiently minimises the complexity of any cognitive processes which are applied, circumventing more restrictive element–capacity limits.

NOTE: See volume two for the concluding chapters of this thesis, along with appendices (including scores and charts for the accompanying compositions).