LERDAHL'S *SURFACE TENSION RULE*: VALIDATION OR MODIFICATION

DEBORAH LENORE HENRY

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ABSTRACT

Lerdahl's *Tonal Pitch Space* (2001) combines music theory with current understanding of music perception and cognition creating of model of tonal pitch space. Lerdahl's goals include quantification of areas of tension and relaxation perceived by listeners experienced in Western tonal music. Tension is associated with instability, distance, uncommon tones, and weak attractional force; relaxation with stability, proximity, common tones, and strong attractional force. Quantification requires creation of a time-span segmentation derived from the metrical grid and grouping analysis of the score. The time-span segmentation is necessary for creating the time-span reduction. The time-span reduction removes structurally less significant elements from the musical surface through a series of steps not unlike the layers of Schenkerian analysis. The ultimate goal is the prolongational reduction accompanied by prolongational tree.

Global tension is quantified by summing values obtained when considering the region in which an event occurs, distance between successive chords revealed by their position on the chordal circle-of-fifths, number of distinct pitch classes between successive chords, tension inherited by subordinate chords from superordinate chords, melodic and harmonic attraction, and surface dissonance. Lerdahl's *Surface Tension Rule* assigns tension added values due to chord Inversion, chord note in the top voice (Melody), and nonharmonic chord tones. This study tested the validity of assigned tension added values for Inversion and Melody asking 82 participants familiar with Western tonal music to rate perceived tension of Major and minor four-note chords heard devoid of tonal and musical contexts.

Results showed Lerdahl's tension added values required modification. Root position chords and chords with the root in the Melody require a tension added value greater than 0. Tension due to First Inversion is not the same as tension due to Second Inversion. Tension due to First and Second Inversion is greater than tension due to the third or fifth of a chord in Melody. Tension due to Second Inversion is not different from tension due to root in Melody. A new category, chord Quality, needed to be added. Expertise did not play a role. Lerdahl's model and these results provide insight for performers, teachers, listeners, and composers.

DEDICATION

To my family, past and present.

ACKNOWLEDGMENTS

I did not write this dissertation alone. I had support and encouragement— from family, friends, and colleagues—whose interest in my work helped sustain me. While this group of well-wishers is too numerous to name individually, I would be remiss if I did not identify a few by name.

I am thankful to have had Dr. Jay Rahn, Dr. Melody Wiseheart, and Dr. Dorothy de Val as my committee members. Their guidance offered me the opportunity to think deeply and creatively. Jay's questions and comments lead me in new and exciting directions. Melody introduced me to wonderful new methods of data analysis, and the members of her lab responded willingly and patiently to all my questions about statistics. I am grateful to Dorothy for her attention to detail and her thoughtful, thought-provoking observations.

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INTRODUCTION

Why would a musician and music theorist conduct a study designed to test the validity of Lerdahl's tension added values as defined by his *Surface Tension Rule*[1]—an aspect of his model of tonal pitch space which quantifies and predicts perceived tension in Western tonal music?

Like many children growing up in the 1960s and 1970s, I was expected to study a musical instrument. In my family that meant the piano and the requisite Royal Conservatory of Music (RCM) exams. When I had achieved RCM grade 8, I began to study my instrument of choice, the pipe organ. Separate from but associated with the higher RCM grades were studies in theory, harmony, counterpoint, analysis, and history. Later, I studied music at university which also included lessons on piano and separate classes in theory, harmony, counterpoint, analysis, and history.

In the preceding paragraph, I deliberately chose to describe the learning and performing of music as separate from the learning of theory and history. History was occasionally discussed with respect to performance, mostly related to elements of style or to recount an interesting 'tidbit' about a composer. By and large, music theory and music making were studied separately. In class, I learned 'rules' of harmony and counterpoint, and analysed the harmony and musical form of pieces of music. Rarely was this related to their impact upon a listener or performer. I was fascinated by what I could discover through analysis but had no sense of what that meant for the performer or the listener. I was moved by performing and listening to music but had no explanation for my reaction.

All this changed dramatically when I discovered the relatively new field of music perception.[2] Armed with an intense interest and desire to learn, I approached Dr. Laurel Trainor at McMaster University to enquire about taking her course in music perception and cognition. Unfortunately, it was not being offered in the school term in which I was available. Fortunately, Dr. Trainor offered to supervise me, suggesting I work through the course material as an independent study. She further suggested I attend her weekly lab meetings. Thus, I began investigating a whole new and exciting world. Among the many new avenues explored were auditory scene analysis, music and emotion, brain activation and music processing, and experimental design. I also found, not surprisingly, some studies were more about psychology than about music. Music was a vehicle for understanding some aspect of interest to psychologists but did not further an understanding for performers, composers, and listeners. In the following term, while pursuing graduate studies in music, I was able to take another course in music perception and cognition which further fuelled my enthusiasm and curiosity.

Next term, back in the music department, I was introduced to the teachings of someone who also opened up a whole new and exciting world. From my first lesson in Schenkerian analysis I felt I had finally found an approach to analysing music that brought the music to life.[3] Schenker's approach came initially from his desire to help his piano students become better performers. Unlike much of my previous education, which looked at the notes and chords in the score sequentially without much concern about their effect, Schenker considered the effect of notes and chords through time. For example, Event 1 could influence our perception of Event 2 but also of Event 10. This was possible because of an important element of Schenker's approach—the appearance and interaction of musical events

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[1] See Chapters 1 and 3 of this paper and Fred Lerdahl, *Tonal Pitch Space* (Oxford: Oxford University Press, 2001),
[2] See Chapter 2 for a discussion of research in music perception as it influences Lerdahl's model of tonal pitch space.
[3] See Chapter 1 for a discussion of Schenker's approach and its influence upon Lerdahl's model of tonal pitch space.

at different layers or levels.[4] According to Schenker, in Western tonal music, much was happening behind the surface of the music contributing to the sense of motion and rest articulated by the performer and experienced by the listener. The more I studied Schenker's approach the more I could relate it to what I had learned and continued to learn about music perception and cognition.

I mentioned, to Dr. Trainor, my ideas of how elements of music perception and cognition were evident in Schenker's approach to music analysis. She suggested I read Lerdahl's *Tonal Pitch Space* as it combined tenets of music theory, including Schenker's layers, with results from experiments in music perception.

So, to return to my opening question, why would a musician and music theorist conduct a study designed to test the validity of Lerdahl's tension added values as defined by his *Surface Tension Rule*? It is because Lerdahl's model of tonal pitch space, as it relates to Western tonal music, combines elements of music theory and of music perception. Bringing both fields together enriches my understanding of the expressive nature of music. It makes me a better performer, a better teacher, and a better listener.

Since *Tonal Pitch Space* won the 2003 distinguished book award from the Society for Music Theory, elements of Lerdahl's model of various pitch spaces[5] have been cited and incorporated into conference papers, journal articles, books, theses, and dissertations. A search using Google Scholar for the frequency of citations for Lerdahl's *Tonal Pitch Space* results in 616 citations, between January 2001 and May 2016. Searching other databases using these same search parameters returned varying results—15 for Music Index[6], 173 for Web of Science, 206 for Psychinfo, and 332 for Scopus. A search of the Proquest database for dissertations and theses returned 93 citations.[7]

Searching Scopus, Psychinfo, and Proquest for Lerdahl and Tonal Pitch Space in bibliography, and "tonal pitch space" also in abstract, returned different numbers.[8] Scopus reported 22 instances when Lerdahl's book was cited and when the phrase "tonal pitch space" appeared in the abstract. Psychinfo, with the same search parameters, reported 7, and Proquest reported 6 dissertations. It would seem many scholars are reading *Tonal Pitch Space* as background for their work. Fewer scholars are using aspects of *Tonal Pitch Space* as the foundation for their work.

Each database categorised the disciplines represented slightly differently. I have combined and summarised some of these categories in Table Intro.1. The totals include articles, books, book chapters, conference papers, dissertations, editorials, letters, and book reviews.[9] The numbers in Table Intro.1 seem to suggest music scholars are more interested in Lerdahl's *Tonal Pitch Space* than those in other disciplines. However, it is important to note there may be some overlap of categories. For example, one entry may be categorised as both music and mathematics. This is apparent when comparing the total reported (Table Intro.1) to the sum of each row. Proquest, for example,

[4] See Chapter 1 for an explanation of Lerdahl's time-span and prolongation reductions which are similar to Schenker's layers.
[5] Besides modeling movement and perceived tension through Western tonal pitch space, Lerdahl also models movement and perceived tension through various chromatic spaces such as octatonic, hexatonic, and atonal space.
[6] This search included Music Index, Humanities and Social Science Index Retrospective, and Humanities International Index, i.e. 15 may be the same 5 documents found in 3 databases.
[7] A word of caution regarding the numbers given here. The results were dependent on how the search terms were classified. Also, some databases were easier to search than others, i.e., I could be more or less specific with the search parameters. My intention is not to provide unassailable evidence but rather to elucidate certain trends in scholarly pursuits.
[8] I did not search all databases using these parameters, as not all databases allowed such refinements.
[9] Scholarly articles outnumber all categories, followed by conference papers and book reviews.

reported a total of entries of 93. The total when summing the entries in each category is 114. However, Table Intro.1 gives a general sense of the breakdown of disciplines interested in aspects of Lerdahl's model.

Table Intro.1.[10]

Entries in databases by category

Database	Count	Acoustics	Computer Science	Mathematics	Music[11]	Psychology[12]
Music Index[13]	15	1	0	0	27	4
Proquest	93	0	8	0	87	21
Scopus	332	8	74	23	193	130
Web of Science	173	3	13	4	111	98

Table Intro.2 shows the analysis of the report for the categories of Music and Psychology among the citations identified in the Music Index and Psychinfo. This comparison raises some interesting points. Recall my experiences of studying music—theory and analysis as separate from performance and the listening experience. This seems to be reflected in the categories identified by the Music Index, the Humanities and Social Science Index Retrospective and Humanities International Index databases. There are no categories of Emotion, Performance, or Music Education. We do find these categories listed by Psychinfo.

Table Intro.2.

Itemisation of some of the Music and Psychology categories of citations in Music Index, Humanities and Social Science Index Retrospective and Humanities International Index, and Psychinfo

Music Index		Psychinfo	
Category	Count	Category	Count
Tonality	8	Music Perception	87
Music Theory	7	Auditory Perception	41
Space and Time	5	Pitch Perception	26
Perception	4	Cognition	23
Pitch	3	Musicians	15
Analysis	2	Emotions	22
Notation	2	Expectations	10
Acoustics	1	Acoustics	8
		Performance	10
		Music Education	5

[10] Google Scholar reports the total entries but does not differentiate among the various sources of the citations.
[11] The broad category of music may include, but is not limited to, musicology, ethnomusicology, theory, and music education.
[12] The broad category of psychology may include, but is not limited to, experimental, developmental, perception, cognition, and neuroscience.
[13] The Music Index database search also included the Humanities and Social Science Index Retrospective and Humanities International Index databases. This may inflate the numbers as the same scholarly work may appear in two or all three of the databases.

A search for citations of Lerdahl's *Tonal Pitch Space*, between 2001 and 2016, in the *Journal of Music Theory* resulted in one entry—a footnote in an article referring to Lerdahl's critique of neo-Riemannian space. The same search in *Music Theory Spectrum, Computer Music Journal*, *Indiana Theory Review*, the *Journal of the American Musicological Society*, and *Music Analysis* returned one entry each—a book review of Lerdahl's *Tonal Pitch Space*. A search for Lerdahl*Tonal*Pitch*Space*2001[14] in *Music Theory Online* returned 64 results. The type of documents cited here included footnotes, dissertations, conference papers, articles, and mention in other books. A brief examination of the articles reveals a variety of topics citing Lerdahl's book, including discussions of musical forces, music perception, and rhythmic structures. The majority of articles referred to Lerdahl's representation of chromatic and atonal spaces.

In the Preface to *Tonal Pitch Space*, Lerdahl says, "I view music theory as a branch of cognitive science. I am concerned ... with proposing [pitch constructs] that model the unconscious intuitions of experiences listeners of the musical idioms under consideration."[15] I do enjoy applying my knowledge and experience to the analysis of musical scores for no other purpose than to discover harmonic, melodic, thematic, and formal elements, and their interactions. It is fascinating to discover how a limited number of pitch classes can be combined creating a limitless number of compositions. However, my appreciation of music as a performer, listener, and teacher is richer when my discoveries are combined with my knowledge of their potential effect as revealed by studies in music perception and cognition. Incorporating results from studies in music perception and cognition with tenets of music theory aid our understanding of how, and what, in music moves us.

The purpose of the study described in the following chapters is to determine the validity of the tension added values Lerdahl assigns to two of three categories contributing to surface tension and, if shown to be necessary, modify his tension added values. So, again, why would a musician and music theorist conduct such a study? Because, paraphrasing Lerdahl, this study provides information contributing to our understanding of musical expression, "a subject that cries out for better understanding."[16]

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[14] The search function on the home page of the journal *Music Theory Online* does not allow for much refinement of a search. Formatting the search term as Lerdahl*Tonal*Pitch*Space*2001 ensured the results to be related to Lerdahl's book. Without linking the search parameters, one could obtain results referring to any mention of Lerdahl and/or tonal and/or pitch and/or space.

[15] Lerdahl (2001), vii.

[16] "I attach special importance to the approach to tonal tension and attraction developed in chapter 4 [this includes his *Surface Tension Rule*] because these conceptions have a great deal to do with musical expression, a subject that cries out for better understanding." Lerdahl (2001), vii.

CHAPTER 1: LERDAHL'S MODEL OF TONAL PI TCH SPACE AND ITS BASIS IN MUSIC THEORY

Introduction

The year 1983 saw the publication of Fred Lerdahl and Ray Jackendoff's *A Generative Theory of Tonal Music* (*GTTM*). In 2001, Lerdahl published *Tonal Pitch Space* (*TPS*), in part to address some of the limitations he perceived were in *GTTM*, and to extend the theory of pitch space to include spaces other than tonal. The object of *GTTM* and *TPS* was to develop a model demonstrating listeners' experience of, primarily but not exclusively, Western tonal music[17]—historically grounded in music theory and reflecting the current understanding of music perception and cognition.

Accordingly, Chapter 1of this paper opens with a discussion of some of the music theorists, and their ideas, relevant to Lerdahl's model of tonal pitch space. Once the music theory background is established, details of Lerdahl's model of tonal pitch space are explained. The experiment discussed in this dissertation is concerned with Lerdahl's *Surface Tension Rule,* i.e., the psychoacoustic affects of chords heard devoid of a musical and tonal context. However, it is necessary to understand Lerdahl's model of tonal pitch space in order to evaluate the effect, on the complete model, of tension added values due to surface tension. Chapter 2 examines the empirical data Lerdahl cites as supporting his model of tonal pitch space. Chapter 3 presents the experiment and results from traditional statistical tests (ANOVA and paired sample *t*-tests) performed on the data. Chapter 4 analyses the data using Effect Sizes and Confidence Intervals—a method supporting the results in chapter 3 and, I believe, more accessible to readers unaccustomed to reading and interpreting statistics. Chapter 5 considers explanations for the results of the study, drawing on facets of Lerdahl's model as well as psychoacoustic models. Chapter 6 considers various methods of modifying Lerdahl's tension added values for surface tension incorporating each into a musical example, drawing on most aspects of Lerdahl's model of tonal pitch space.

Music Theorists

Among the earlier music theorists from whom Lerdahl derives inspiration for his theory of tonal pitch space are Aristoxenus (c375/360 - ? BCE), Jean-Philippe Rameau (1683-1764), Gottfried Weber (1779-1839), Heinrich Schenker (1868-1935), and Ernst Kurth (1886-1946).[18] Although there is diversity of era, education, and nationality among these theorists, a commonality found in their writings is, as with Lerdahl, an attempt to explain listeners' experience of music through analysis of the music.[19] For example, all the above theorists refer to and speculate upon the causes of the experiences of motion in music, and of musical tension and relaxation or repose. Rameau, Weber, and Lerdahl describe progressions in which common tones occur as being closely related, thus exhibiting less tension

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[17] "I am concerned not just with creating intellectually or aesthetically pleasing pitch constructs but also with proposing ones that model the unconscious intuitions of experienced listeners of the musical idiom under consideration." Fred Lerdahl, *Tonal Pitch Space* (Oxford: Oxford University Press, 2001), vii.

[18] Lerdahl acknowledges Rameau and Schenker, makes reference to Weber and his *Chart of Regions*, and to Kurth's potential and kinetic energies, but does not refer to Aristoxenus. I included a discussion of Aristoxenus for two reasons. Aristoxenus is an early thinker about the expressive character of music. Much of his theorising is in line with Lerdahl's.

[19] This characteristic differentiates this group of theorists, who look to the music itself for answers, from theorists who look to the properties of sound and physiology of the ear for their answers. The former field came to be called *Musikpsychologie* and the latter *Tonpsychologie*. Most aspects of Lerdahl's model of tonal pitch space would be classified as *Musikpsychologie*. His *Surface Tension Rule*, the subject of this dissertation, would be classified as *Tonpsychologie*.

as the music moves from one chord (or region) to the another chord (or region). Aristoxenus, Kurth, and Lerdahl discuss attractions between pitches. They note some pitches are more attracted to certain pitches than they are to other pitches.[20] They conclude strength of attraction is related to the experience of motion and of tension. Weber and Lerdahl discuss chordal and regional distances. They categorise chords and regions as more or less closely related. The closer the relationship is determined to be, the smaller the distance between the two events, and the lower the amount of tension experienced as the music moves from one chord or region to another. Stability, harmonic and melodic, is an important concept for all these theorists.[21] Lerdahl groups these dichotomies under the contrasting metaphors of tension and relaxation. Tension is associated with instability, distance, uncommon tones, and weak attractional force. Relaxation is associated with stability, proximity, common tones, and strong attractional force.

Aristoxenus,[22] Rameau,[23] Weber,[24] Schenker,[25] and Kurth[26] —each with their own biases and characteristic terminology—attempt to identify, qualitatively, characteristics of music that affect listeners' experience. Lerdahl makes use of aspects of these qualitative analyses to support his model of tonal pitch space, a model that is quantitative and empirically testable. Discussed below are of some of the ideas proposed by earlier theorists that relate to elements of Lerdahl's model of tonal pitch space.

Approaching the theorists chronologically, we begin with the anti-Pythagorean Aristoxenus. Aristoxenus was interested in understanding and explaining the sense of motion perceived when listening to music. He put his trust in his ear and not the ratios endorsed by the Pythagoreans. Aristoxenus' quest led him to formulate his theory of *dynamis*. Gibson, in *Aristoxenus of Tarentum and the Birth of Musicology*, says, "dynamis ... has a variety of meanings ranging from power, might, or force to ability, faculty, or potential. Aristoxenus uses it to refer to his conception of the role of a note within a system ... and it is often translated in a musical context as 'function'."[27] The

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[20] In the case of Aristoxenus, which pitch best follows a particular pitch.
[21] Aristoxenus was concerned only with melody.
[22] Aristoxenus, in book II, explains how his approach to music analysis differs from his predecessors "some of whom … [are] dismissing perception as inaccurate … without even properly enumerating the perceptual data. We, on the other hand, try to adopt initial principles which are all evident to anyone experienced in music." Aristoxenus in *Greek Musical Writings Volume II: Harmonic and Acoustic Theory*, ed. Andrew Barker, (Cambridge: Cambridge University Press, 1989), 149-150 (32.19-32.28).
[23] When Rameau began writing about music, he spoke of the roles of experience and reason, alternating between which was most important. By the end of his career, he returned to his initial belief saying, when reason and experience conflict, "[w]e may judge music only through our hearing; and reason has no authority unless it is in agreement with the ear." Jean-Philippe Rameau, *Treatise on Harmony*, trans. and ed. Philip Gossett (New York: Dover Publications, 1971), 139.
[24] Saslaw describes how Weber analyses an entire work, "demonstrating in the process his interest in investigating the perceptual bases for hearing harmonic events." Janna Saslaw, "Gottfried Weber and the Concept of *Mehrdeutigkeit*," (PhD diss., Columbia University, 1992, ProQuest (AAT 9221209), 252.
[25] Robert Snarrenberg says, "Schenker's theory amounts to a probing analysis of music cognition" and describes Schenker's "theory [as] consistent in its approach with the most recent advances in the understanding of perception." Robert Snarrenberg. "Schenker, Heinrich." In *Grove Music Online*. *Oxford Music Online*, http://www.oxfordmusiconline.com.ezproxy.library.yorku.ca/subscriber/article/grove/music/24804 (accessed April 14, 2008).
[26] "Experiencing the music directly through its affective impact, without unnecessary intellectualizing, was in Kurth's mind paramount to musical comprehension." Lee Rothfarb, "Ernst Kurth as Theorist and Analyst" (PhD diss., Yale University, 1985, ProQuest AAT 8602156), 34.
[27] Sophie Gibson, *Aristoxenus of Tarentum and the Birth of Musicology,* ed. Dirk Obbink and Andrew Dyck, Studies in Classics (New York and London: Routledge, 2005), 8.

role of *dynamis* in perceived motion between tones of a melody is related to Lerdahl's concept of tonal function. Both Aristoxenus and Lerdahl acknowledge the hierarchy among tones established by a scale or tonal context. Their function (of a tone for Aristoxenus; tone, chord, and region for Lerdahl) is dependent upon musical context.

Many of the ideas found in Rameau's influential treatises on music theory inform Lerdahl's model. Rameau's views on chord inversion, the concept of the fundamental bass, the sense of repose at cadences, the power of the leading tone, the salience of the first (P8) and second overtones (P5) of the harmonic series, the identification of vii^{o} as a rootless V^{7}, the tonic as aural reference point and source of compositional unity,[28] dissonance associated with seventh chords, and the concept of melodic attraction are made use of by Lerdahl.[29]

Weber's *Mehrdeutigkeit* (theory of Multiple Meaning), his *Principle of Simplicity*, his *Principle of Inertia*, and his *Chart of Regions* are particularly relevant for Lerdahl's model. Lerdahl incorporates Weber's observations regarding the potency of relationships between various regions, the perceived distance between regions, the best paths through regional space,[30] the centricity of the tonic, the perceived stability of chords in root position and inversions. Lerdahl acknowledges only Weber's *Chart of Regions*.

Lerdahl admits aspects of his theory bear a resemblance to some of Schenker's views, yet enumerates ways in which his theory of tonal pitch space is superior to Schenker's theory. Score reduction, in the horizontal and vertical dimensions, determined by event hierarchies, is employed by both Schenker and Lerdahl. This results in layers in which the remaining chords, prolonged over time, denote increasing structural stability. Lerdahl's final layer, I-V-I, depicting the initial rise in tension (I→V) and the final descent to relaxation (V→I), is reminiscent of Schenker's *Ursatz*. Schenker similarly describes the two-part structure with its representation of motion, tension, and relaxation.

Melodic attraction was of supreme interest to Kurth. His theorising regarding the varying strengths of attraction between various melodic pitches and the role of harmony in impeding this forward motion are captured in Lerdahl's theory of melodic attraction. Also relevant are Kurth's concepts of *Scheinstimme* (apparent voices),[31] *Grundpfeiler* (harmonic pillars),[32] and *Fortspinnung* (spinning forward).[33]

While Lerdahl's theory of tonal pitch space is influenced by more theorists than those listed above, and by other aspects of the above theorists, I have chosen to discuss the ideas I believe to relate most significantly to

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[28] Weber, Schenker, and Kurth acknowledge this as well. As mentioned above, Aristoxenus has his own version of this relating it to tetrachords.

[29] Rameau introduces the idea of melodic attraction referring primarily to semitonal attraction between ^7 and ^8 and between ^4 and ^3. Lerdahl expands this significantly in his theory of melodic attraction.

[30] The 'best' path is the shortest and most efficient path resulting in the lowest tension values.

[31] This idea is similar to Weber's 'part-breaking' or composite melody. Schenker also discusses the occurrence of composite melodies. Tangentially related is also Schenker's concept of linear progressions in which non-adjacent pitches are seen and heard as related to one another through the process of unfolding. Lerdahl's prolongational analysis and prolongational tree, with its linking of events separated in time, has similar characteristics to Weber, Schenker, and Kurth's concepts.

[32] This concept is similar to Rameau's Fundamental Chords (I, IV, and V), Weber's 'essential harmonies,' and Schenker's contemporaneous theory in which he proposes the occurrence of certain vertical chords creating structural harmonies, or scale-steps. Lerdahl repeats structural chords through the layers of prolongational analyses.

[33] For Kurth, a melodic motive is propelled forward by kinetic-linear energy, resulting in the creation of a theme; a theme is propelled forward creating a phrase; a phrase is propelled forward creating more phrases the end result of which is a complete piece of music which comes to final rest at its conclusion.

Lerdahl's model. Consequently, I refer to what I consider the most relevant theories of the above earlier theorists throughout this examination of Lerdahl's theory of tonal pitch space. In some instances, Lerdahl draws these parallels himself. In other instances, I do so.

Lerdahl's theory of tonal pitch space attempts to quantify the forces of attractions between melodic and harmonic pitch classes. To this end, four types of hierarchical structures are introduced in *GTTM* and retained in *TPS*. They are a) grouping and metrical structures, b) time-span segmentation, c) time-span reduction, and d) prolongational reduction. New in *TPS* are the stability conditions, which Lerdahl describes as "the centerpiece of this [*TPS*] study."[34] They are important for establishing event hierarchies in both types of reductions. New also to *TPS* is Lerdahl's theory of melodic attraction.

Figure 1.1[35] is a flow chart illustrating the integration of the four components, not including any feedback effects, introduced in *GTTM*, plus the stability conditions of *TPS*. This figure demonstrates how the grouping[36] and metrical[37] structures aid the listener in the formation of the time-span segmentation.[38] This interaction allows for "the dominating-subordinating relationships of the time-span reduction [to] take place; and from the time-span reduction the listener projects the tensing-relaxing hierarchy of prolongational reduction."[39] Both the time-span reduction and the prolongational reduction are subject to the stability conditions.[40] These structures and the stability conditions are discussed in detail below, preceded by an overview of *TPS*.

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[34] Fred Lerdahl, *Tonal Pitch Space* (Oxford: Oxford University Press, 2001), 4.
[35] Lerdahl (2001), Figure 1.2, 4.
[36] Listeners group musical units into motives, phrases, sections. Lerdahl's grouping rules are based primarily on Gestalt principles of proximity and similarity. Related to these ideas is Kurth's discussion, in *Grundlagen des linearen Kontrapunkts:Einführung in Stil und Technik von Bach's melodische Poyphonie* (Foundations of Linear Counterpoint: Introduction to the Style and Technique of Bach's Melodic Polyphony), of what he terms *Fortspinnung* or 'spinning forward'. Kurth argues a melodic motive is propelled forward resulting in the creation of a theme. A theme is propelled forward creating a phrase. A phrase is propelled forward creating more phrases, the end result of which is a composition. Lerdahl's grouping analysis attempts to identify the boundaries of each of these.
[37] The metrical structure depicts the hierarchy of strong and weak beats.
[38] The time-span reduction is based upon the interaction of pitch and rhythm, and aids in the determination of the positions of structurally important events at all levels. Lerdahl claims this is one of the facets of his model of tonal pitch space which makes it superior to Schenker's approach.
[39] Lerdahl (2001), 4.
[40] The stability conditions, based primarily on tenets of music theory, aid in determining which events are most stable and are thus retained in the next level of the reduction.

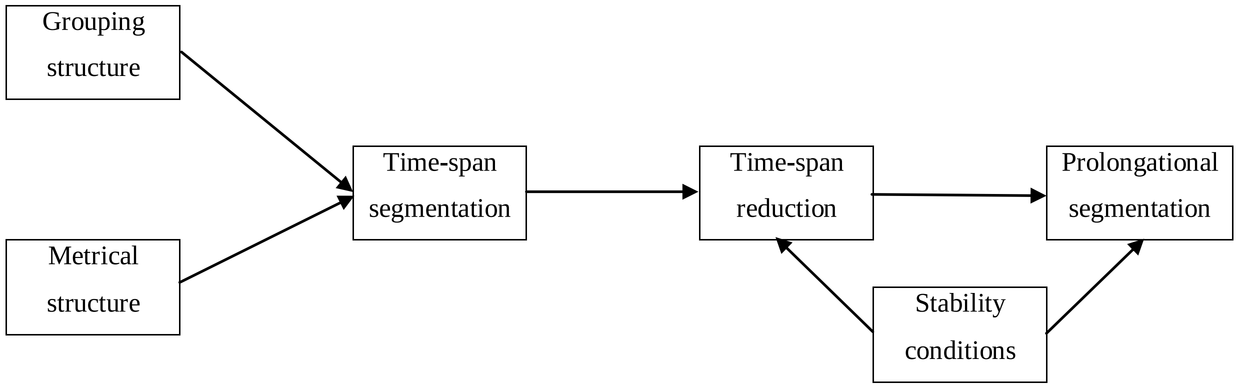

Figure 1.1. A flow chart showing the integration of the four hierarchies (metrical and grouping structures form one unit). See Appendix A for a musical example of these structures.

Tonal Pitch Space – the book

In his first chapter, *Theoretical Foundations*, Lerdahl reviews the main points of *GTTM*, presents an analysis incorporating these elements, elaborates on prolongational theory, and list topics that have been updated or expanded upon in *TPS*. In chapter 2, *Diatonic Space*, Lerdahl unveils his new material. His concept of three interacting pitch spaces—pitch class, chordal, and regional—is described and given historical music theoretic and psychological foundations. In chapter 3, *Paths in Pitch Space*, Lerdahl applies his model to musical scores, determining and charting pathways of each type of pitch space. Models of harmonic tension, along with theories of harmonic and melodic attraction, are developed in chapter 4, *Tonal Tension and Attraction*. As with the previous chapters, Lerdahl supports his models with historical music theoretic precedents and research in cognitive psychology, and applies the models to sample analyses. Chapter 5, *Prolongational Functions*, describes the method for finding a tonic, both local and global, and presents Lerdahl's concept of chord functions. The remaining three chapters, *Chromatic Tonal Spaces*, *Prolongations in Chromatic Spaces*, and *Atonal Structures* are not germane to our discussion of tonal pitch space and will not be discussed in this study. Before examining the particulars of Lerdahl's model of tonal pitch space (his chapters 2-5), some relevant details premiered in *GTTM* and discussed in chapter 1 of *TPS*, will be summarised, followed by an account given of the hierarchical structures found in the Figure 1.1.

After his brief overview of the hierarchical structures, Lerdahl records five assumptions incorporated into *GTTM* and "analogous to those found elsewhere in cognitive science."[41] Of the five assumptions, Lerdahl believes "[m]ost music theorists tacitly accept [the first] three simplifying assumptions."[42] The first assumption identifies the musical sound under consideration as the "aural perception of pitches, timbre, durations, and dynamics"[43] and not the characteristics of the acoustic signal—in other words, in the tradition of Aristoxenus and not the Pythagoreans. Related to this assumption is the acceptance of the notated musical score as a representation of the musical sounds'

[41] Lerdahl (2001), 5. Lerdahl continues to support his model by referring to the practices established through research in cognitive theory. It is important to Lerdahl that he is able to demonstrate his model is based upon how and what experienced listeners hear.
[42] Lerdahl (2001), 5.
[43] Lerdahl (2001), 5.

pitches and their durations. Lerdahl recognises the limitations of the score but believes, with the addition of harmonic and functional analyses, the musical score may represent the musical surface experienced by listeners.

Secondly, Lerdahl's model of tension and relaxation assumes an experienced listener, where experienced means a listener familiar with the idiom under consideration. To this end, the model characterises the general way in which the music is heard, recognising no two individuals necessarily hear the same music in the same way, nor does one individual necessarily hear the same music exactly the same way twice. Thus, while each experience of a piece of music may be different at some level, the experience is based upon common characteristics found in the score and accounted for in Lerdahl's model.

The third assumption is, at first, puzzling. Lerdahl indicates he is not attempting to describe the experience of music "heard as it unfolds in time but [instead] the final state of a listener's understanding."[44] Yet he calculates sequential harmonic and melodic tensions.[45] Lerdahl's reference to Jackendoff (1991) clarifies this matter. Jackendoff's depiction of hearing music as it unfolds is reminiscent of Weber's concept of *Multiple Meaning* where Weber describes the decisions 'the ear' undergoes when presented with chords in a musical context. For example (representing both Jackendoff and Weber), when presented with a C-E-G chord at the onset of a piece, the listener assumes this is the tonic chord. If this is followed by an F-A-C chord, the listener is now faced with several choices. Does C-E-G followed by F-A-C represent I/**C**[46] and IV/**C** respectively, V/**F** and I/**F**, or (less likely but possible) III/**a** and VI/**a**? Unlike Weber, Jackendoff and Lerdahl include the meter and grouping as resources available to aid the listener. The third assumption, therefore, is depicting the most likely decisions of the listener or, as Lerdahl says, "the final state of the listener's understanding."

Lerdahl records two additional assumptions. The first concerns the concept of hierarchical structures. He defines hierarchical organisation as "discrete elements such that one element is perceived to subsume or contain other elements. The elements do not overlap, subsumption is recursive, and at any given level the elements are adjacent."[47] In the time-span and prolongational reductions, the most stable elements at one level are found in the next higher level while the least stable are not, as they are subsumed by the more stable events.[48] Once subsumed, the element does not reappear.

The fifth and final assumption of *GTTM* results in the exclusion of polyphonic writing as, according to Lerdahl and Jackendoff, chords, unlike melodic lines, are organised hierarchically.[49] In *TPS*, Lerdahl suggests his theory of melodic attraction addresses this concern as it considers the horizontal dimension. As we shall see, the theory of melodic attraction is applied to all voices and not solely the most salient voice.

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[44] Lerdahl (2001), 5.
[45] Sequential events are temporally consecutive events.
[46] Here I am following the convention Lerdahl uses in *TPS* where the chord is represented by Roman numerals placed over a bolded letter, representing the region in which the chord is found. I also follow Weber's chord labelling system where upper case indicates major and lower case indicates minor.
[47] Lerdahl (2001), 5.
[48] This is true also for the metrical and grouping structures.
[49] Much of Kurth's writings are in response to this dominant perspective of music theory. For Schenker, the horizontal dimension is important also. He accuses Rameau of verticalising and thus stagnating music theory.

Lerdahl claims it is necessary to allow these five assumptions, “analogous to those found elsewhere in cognitive science,”[50] simplifying the complex musical signal, “in order to formulate suitable insights and generalizations.”[51] The effects of timbre, variations in performance, mental state of listener, and listening environment are some of the factors not addressed by Lerdahl’s model. Instead, he invokes these five assumptions, accepted by cognitive science and music theory, thereby simplifying the musical signal, and rendering it manageable.

The Four Hierarchical Structures

In contrast to what Lerdahl describes as Schenker’s informal approach to reduction, Lerdahl and Jackendoff create three types of rules that can be applied to each hierarchical structure. They are well-formedness rules (WFR), transformational rules (TR), and preference rules (PR). The well-formedness rules “establish the strict hierarchical organization of each component.”[52] Transformational rules allow hierarchically ill-formed phenomena to be modified and, in the process, become well formed.[53] Preference rules “do the major work of analysis within the theory [and] pick out features in the music that influence the listener’s intuitions.”[54] This is because PRs are based upon how listeners are likely to hear the music. Lerdahl indicates PRs do not predict rightness or wrongness of a particular analysis. Instead, PRs suggest which, of the various alternatives, is the most likely.[55] *TPS* formulates more rules such that, continuing the imperative of *GTTM*, the rules must be predictive enough to allow empirical testing.[56]

WFRs, TRs, and PRs applied to analyses of the musical score, govern grouping structure, metrical structure, time-span reduction, and prolongational reduction. Grouping analysis is indicated by square brackets placed under the score. The brackets are hierarchical in nature, with the brackets representing the longer phrases placed below (subsuming) the shorter phrases above. Analysis of the interaction of meter and rhythm, i.e. the metrical grid, is represented by dots placed under the score. Once again, the representation is hierarchical with each smaller note value being subsumed by larger note values. Salience of grouping and metrical structures is dependent upon tempo. Shorter events are less salient as tempo increases.

The time-span reduction takes grouping and metrical structure into account, is hierarchical in nature, but is based upon chord relationships and relative harmonic stability. In a manner similar to the above structures, the most stable pitch events of a level of grouping structure are represented at the next higher level or segment, while less stable pitch events are not. Time-span reduction places chordal reductions under the musical score, and as with the grouping and metrical structures, the staves showing the most stable events are placed below those of the less stable events. A tree-like structure, placed above the score, represents the hierarchical reductions established in the prolongational reduction below the score. The branching of this structure indicates which events are subordinate or

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[50] Lerdahl (2001), 5.
[51] Lerdahl (2001), 5. Creating sound stimuli in piano tone is a common method of 'simplifying the complex musical signal.' Doing so helps to limit the number of variables that may be responsible for the results of an experiment. For example, the piano tone is more consistent throughout the change in registers than are some other instruments.
[52] Lerdahl (2001), 6.
[53] One of the grouping well-formedness rules states: if Group 1 ends with event *i* and Group 2 begins with event *j*, event *i* and event *j* cannot be the same event. Grouping overlap violates this well-formedness rule. It occurs when Group 1 ends with event *i* and Group 2 begins with event *i*. The transformational rules allow the well-formedness rule to be broken when demanded by the listening experience of the music.
[54] Lerdahl (2001), 6.
[55] Weber’s *Principle of Simplicity* (see footnote 101) and *Principle of Inertia* (see p. 30) also function in this manner.
[56] Lerdahl (2001), 7.

superordinate to other events. If, for example, event 1 (e_1) precedes event 2 (e_2) and e_2 is a right branch to e_1, then e_2 is subordinate to or an embellishment of e_1 (See Figure 1.2 a, b, and c).[57] Similarly, if e_1 succeeds e_2 and e_2 is a left branch to e_1, then e_2 is subordinate to or an embellishment of e_1 (See Figure 1.2 d, e, and f).[58] Lerdahl chooses to suppress the tree notation of the time-span reduction in favour of the prolongational reduction as the latter includes the former, and also includes information about relative tension and relaxation.[59]

Like the time-span reduction, the prolongational reduction is hierarchical, and consists of two components. Once again, the pitch reduction is below the musical score and the tree structure is above the musical score. Unlike the time-span reduction, which retains chordal notation, the prolongational reduction notates only the more salient bass and soprano, creating both horizontal (removing subordinate events) and vertical reductions (removing interior chord pitches).[60] Prolongational relationships are shown by the tree structure above the musical score and by slurs between note heads in each level of the prolongational reduction.

As stated above, like the time-span reduction, the prolongational reduction incorporates a tree structure depicting hierarchically more and less stable events. Unlike the time-span reduction, the prolongational reduction indicates areas of relative tension and relaxation with the addition of circles at prolongation branching points. Right and left branchings continue to indicate embellishment of and subordination to more harmonically stable events, with right branching indicating tension (moving from one more stable event to a less stable event), while left branching indicates relaxation (moving from a less stable event to a more stable event).

As shown in Figure 1.2 below, Lerdahl establishes three categories of tension—strong prolongation (represented by an unfilled circle), weak prolongation (represented by a filled circle), and progression (represented by no circle). A strong prolongation occurs when the second event is a repetition of the first event (e.g. I with the third of the chord found in the melody, $I^{\wedge 3}$, is followed by another $I^{\wedge 3}$). A weak prolongation occurs when the second event is an altered form of the first. This can be either a change in inversion and/or a change in the melody note. An example of this is $I^{\wedge 3}$ followed by $I^{\wedge 5}$ or by I^{6}. A progression occurs with a change in harmony. Two events deemed a progression convey more tension than do events of a weak prolongation, which convey more tension than do events of a strong prolongation. Left branching, similarly categorised and similarly identified (with and without circles), conveys relaxation.

[57] Unlike the prolongational branchings shown in Figure 1.2, time-span branchings do not include filled and unfilled circles, and thus do not distinguish among strengths of tension/relaxation.
[58] See footnote 57.
[59] The difference between the tree structure of the time-span reduction and that of the prolongational reduction is explained below and in Figure 1.2.
[60] Rameau and Schenker, in their writings, also comment upon the salience of the outer voices.

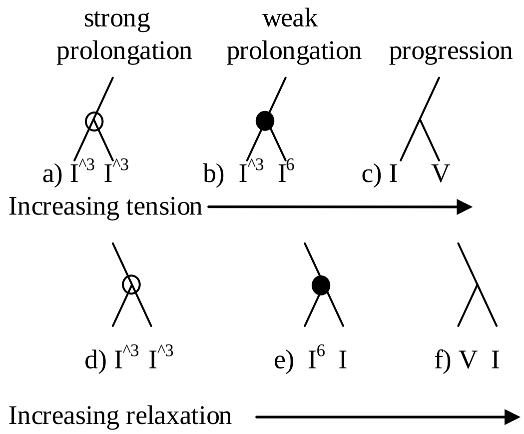

Figure 1.2. Prolongational branchings indicating relative tension and stability.[61, 62]

Areas of tension or relaxation are shown also between horizontal pitch events of the prolongational reduction. Here, strong prolongations are indicated by dotted slurs connecting horizontally, pitches of the soprano and of the bass, weak prolongations by a dotted slur connecting one set of horizontal pitches and solid slurs joining the other horizontal pitches, and progressions by solid slurs connecting both the horizontal pitches.

Lerdahl is not the first theorist to employ the term ‘prolongation.’ In musical theoretic circles, the term is found most often in the context of Schenker. Lerdahl, at once, associates and separates his theory from that of Schenker’s. He notes Schenker’s use of the term is “open to debate,”[63] but indicates a frequent meaning is that of ‘composing out.’ *GTTM* employs the term ‘elaboration’ when referring to the idea of composing out. When used in *GTTM*, however, ‘prolongation’ refers to the elaboration of an event by another event that “is either literally or functionally identical … reflecting ordinary English usage.”[64] We see this usage in the examples of strong and weak prolongation given above—$\mathrm{I}^{\wedge 3}$ is strongly prolonged by a subsequent $\mathrm{I}^{\wedge 3}$ (literally and functionally identical) and weakly prolonged by I^{6} (functionally identical).

At the same time, the meaning of “prolongational reduction” in *GTTM* “is closer to the Schenkerian one.”[65] Lerdahl’s description of his own prolongational analysis as “pervasive[ly] top-down,”[66] is the same as his somewhat critical classification of Schenker’s approach. The difference, for Lerdahl, is due to the method from which the prolongational reductions are derived. According to Lerdahl, top-down prolongational reduction in *GTTM* is based upon the bottom-up time-span reduction (based on grouping and metrical structure, with well-formedness and preference rules, and to which stability conditions are applied) while Schenker’s prolongational reductions are predetermined by the a priori existence of the fundamental structure.

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[61] Lerdahl (2001), 14. The chord examples are not included in Lerdahl's example. They were added by this author.
[62] See Appendix N for more detailed explanation of prolongational branching.
[63] Lerdahl (2001), 15.
[64] Lerdahl (2001), 15. Schenker's use of the term prolongation refers to elaboration of the background tonic chord. This occurs through the addition of passing notes and neighbour notes (and other devices) in the middleground layers arriving finally at the foreground.
[65] Lerdahl (2001), 15.
[66] Lerdahl (2001), 10.

How are the four elements—metrical and grouping structures, time-span reduction, prolongational reduction, and the tree structure of the prolongational analysis—displayed with respect to the musical score? The metrical analysis is placed directly beneath the score. The grouping analysis is found below the metrical structure. Under these analyses is placed the chordal time-span reduction, under which is found the bass-and-soprano prolongational reduction. Above the musical score is the prolongational tree. Each of these structures tells us something different about the final state of the listening experience. The prolongational tree, with its expression of hierarchical relationships between chords and its depiction of tension and relaxation, is the focus of *TPS*. It is through this structure that Lerdahl is able to calculate sequential and hierarchical tension values. These values can be plotted (tension versus musical event), visually depicting listeners' experience of the music. The calculation of tension values brings us to Lerdahl's model of tonal pitch space.

Tonal Pitch Space – the model

As previously mentioned, Lerdahl considers spaces in addition to tonal space. His model, however, originates with tonal space; a space he later adapts for other pitch spaces such as chromatic and hexatonic. The structures discussed to this point are known as event hierarchies. Knowledge of a different type of hierarchy—tonal hierarchy—however, is necessary for understanding Lerdahl's pitch space model. Tonal hierarchies differ from event hierarchies, as tonal hierarchies incorporate a box from Figure 1.1 not yet discussed—the stability conditions. Tonal hierarchies are atemporal and are based on experiences accumulated through listening to tonal music. In this way, tonal hierarchies represent "more or less permanent knowledge about the [tonal] system."[67]

Lerdahl prefaces his own model of diatonic space by referencing and assessing historical models of tonal hierarchy such as Heinichen's (1683-1729) regional circle,[68] Kellner's (1670-1748) regional circle,[69] Weber's *Chart of Regions*,[70] and Riemann's (1849-1919) *Tonnetz*.[71] Rameau is mentioned for his theory of fundamental bass and root progressions.[72] Lerdahl is concerned the above models do not accurately depict cognitive proximity as demonstrated by research in psychology. Nor does Lerdahl believe one model can accurately depict the perceived proximity of each of pitch class, chordal, and regional space.

[67] Lerdahl (2001), 41. Lerdahl states both event and tonal hierarchies depend upon exposure to tonality. A tonal hierarchy exists outside of a specific piece while each event hierarchy exists only in relation to a specific piece.

[68] Heinichen's regional circle combines the circle of fifths for major and minor keys into one circle. Thus, C is followed by its relative a, then C's dominant G and its relative (and a's dominant) e, followed by G's dominant D and its relative (and e's dominant) b, et cetera.

[69] Kellner creates two regional circles. The circle of fifths of the minor keys is placed inside of the circle of fifths of the major keys, with the relative minors and majors placed across from one another.

[70] The vertical axis of Weber's *Chart of Regions*, like the circle of fifths (on which Lerdahl bases his calculations of chordal and regional distances), proceeds by P5s, i.e. C→G→D→et cetera. The horizontal axis alternates tonic major and tonic minor with relative major and minor, i.e. C→c→E^b→e^b→G^b→et cetera. Lerdahl's geometric model of regional space is identical to Weber's *Chart of Regions*.

[71] The horizontal axis is consecutive major thirds. The vertical axis is consecutive perfect fifths. The south to north diagonal axis is consecutive minor thirds.

[72] Lerdahl cites Rameau's theory of fundamental bass as an example of chord relatedness. In his theory, Rameau indicates the pitches of a chord—third, fifth, and seventh—are generated by the fundamental bass or root. His theory of fundamental bass also prescribes the most acceptable root movements—by thirds, fourths, fifths, or sixths—that create the most successful chord progressions. These progressions create common tones between chords, e.g. the root movement of a third in the I/**C**→iii/**C** progression keeps the pitches G and E while exchanging a C for a B. Similarly, I/**C**→IV/**C** retains C as a common pitch. The progressions I/**C**→ii/**C** and I/**C**→vii^o/**C** have no common pitches. The concept of common tones is crucial to Lerdahl's theory of distances in chordal space.

Lerdahl considers his model of tonal pitch space an improvement upon its predecessors for the following five reasons.[73] First, unlike the models mentioned above, in his multidimensional model "spatial distance equals cognitive distance."[74] Consider Weber's model where, regardless of the space (pitch class, chordal, regional), a and G are seen as equally close to C.[75] G is one vertical step north of C and a is one horizontal step west of C. We shall see, in Lerdahl's basic pitch class space,[76] A is 5 (3 vertical plus 2 horizontal) steps from C while G is 2 (one horizontal and one vertical). In chordal space, a's distance is 9 and G's is 7.[77] In regional space, the calculated distance of both a and G is 7.[78] The distance to C from a and from G varies depending on the space under consideration. According to Lerdahl, we hear the pitch class a closer to pitch class C than we hear the chord a or the region a in relation to the chord and region C. This is, for Lerdahl, evidence for his claim that in his model "spatial distance equals cognitive distance"[79] and his model, unlike previous models, can accurately portray all three spaces in one model.

Lerdahl's model is algebraic such that, like with the event hierarchy, "more stable elements at one level repeat at the next larger level."[80] This second provision allows for a weighted evaluation of pitch classes, chords, and regions. Those more structurally important components are retained through to the level of their influence. His third requisite for a cognitively valid model is the incorporation of the three levels of space into one model. This model, as stated in the first condition, must represent the relative distances between elements at each level. The model must be capable of demonstrating the interconnectedness of levels. This condition combines aspects of the first and second requirements while stipulating the necessity of their incorporation into one all-encompassing model.

The chromatic collection must be considered but one level in the hierarchy and not as "the parent structure."[81] Lerdahl's contention, with this fourth condition, is in his model, the asymmetrical diatonic collection and the triad have "at least comparable prominence."[82] Lerdahl is addressing features of pitch class set theory in which no one pitch class has prominence over another, and the chromatic collection is the source of all other collections among which are the diatonic and triadic collections. In pitch class set theory, the diatonic scales and triads are considered subsets of the chromatic collection. [83]

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[73] Lerdahl's five reasons are found in *TPS*, pp. 46-47. They reflect concepts developed in *GTTM* as well as the new formulations introduced in *TPS*.
[74] Lerdahl (2001), 46.
[75] Weber writes lower case a because he is actually referring to the region of a minor and upper case G because he is referring to the region of G major.
[76] See p. 16 for a discussion of Lerdahl's pitch class space, p. 19 for Lerdahl's chordal space, and p. 23 for Lerdahl's regional space.
[77] The 'a' of chordal and regional space is written as in lower case as it is a minor chord in C major, For the same reason, the key of a minor is compared with that of C major in regional space.
[78] Here, measuring distances in regional space, Weber and Lerdahl agree. Lerdahl's point is that, while Weber's space may predict distances in regional space accurately, the same model cannot predict accurately pitch class space or chordal space.
[79] Lerdahl (2001), 46.
[80] Lerdahl (2001), 46.
[81] Lerdahl (2001), 47.
[82] Lerdahl (2001), 47.
[83] The chromatic collection is <0,1,2,3,4,5,6,7,8,9,10,11>. The major diatonic scale, <0,2,4,5,7,9,11>, and the minor triad <0,3,7>, are subsets of the chromatic collection.

Remaining within the domain of set theory for the moment, pitch class sets may be manipulated through the application of interval cycles.[84] Lerdahl stipulates, "interval cycles other than the fifth should not play a central role in the model"[85] thereby reintroducing the circle of fifths, prevalent in tonal theory, and found in the geometric models of tonality created by Heinichen, Kellner, Weber, and Riemann mentioned above.

Lerdahl's fifth condition harkens back to the impetus behind *GTTM* and *TPS*. Lerdahl views "music theory as a branch of cognitive science."[86] The fifth condition is stated, without elaboration, in a single sentence, as if self-evident. After presenting historical musical models and highlighting their limitations by referencing research in psychology, Lerdahl simply records, "the model should mirror empirical findings."[87] This statement carries with it two implications. The first is, as stated above by Lerdahl, music theory should be informed by cognitive science. Lerdahl supports his model of tonal pitch space with evidence from cognitive science. Secondly, Lerdahl has created a theory from which empirical findings may be obtained.

His model is comprised of three integrated spaces—pitch class, chordal, and regional. Each will now be discussed.

The Pitch Class Space[88]

Lerdahl's "basic space"[89] consists of five levels, *a* to *e*, with *a* being the most stable and *e*, the least stable. Level *a* is the root of the triad, *b* the fifth, *c* the triad, *d* the diatonic collection, and *e* the chromatic collection. Dissonance and instability increase as we move down, from *a* to *e*, through this space. Each level, beginning with level *a* and moving towards level *e*, is cumulative as pitch classes presented at the most stable level, *a*, are repeated at the lesser stable levels. This description depicting levels of stability resembles Lerdahl's description of the four hierarchical structures (grouping and metrical, time-span segmentation and reduction, and prolongational reduction) discussed above. In all cases, (basic space and the above structures) only the most stable events continue to the higher next level. Thus, the root of a triad is more stable than is its fifth, which is more stable than is its third, which is more stable than the diatonic collection, which is more stable than the chromatic collection.[90] Lerdahl does not include a level for seventh chords, as the seventh is "a local dissonance governed by voice-leading principles."[91] The other possible option is to include the seventh at the triadic level.[92]

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[84] Interval cycles are applications of intervals to a set returning the set to its original makeup. For example, an application of the interval cycle of 3 to <0,3,6,9> initially results in <3,6,9,0>. Continued applications will return the set to <0,3,6,9>.
[85] Lerdahl (2001), 47.
[86] Lerdahl (2001), vii.
[87] Lerdahl (2001), 47.
[88] This space is represented by *k* in later formulae.
[89] This is the term Lerdahl uses to describe his hierarchical model of pitch classes.
[90] Rameau, with his theory of the root as generator of the pitches of the triad, and Schenker, with his explanation of the formation of the *Chord of Nature* (the major triad), describe a similar hierarchy. Rameau, Schenker, and Lerdahl turn to the overtone series to support their claims of stability and/or salience.
[91]Lerdahl (2001), 47.
[92] Lerdahl decides to consider the added 7ths as surface dissonances (see p. 33).

In Figure 1.3 are two examples of the basic space. Both portray I/**C** (or I/**I**), one with letter names, the other using pitch classes (pcs). Lerdahl believes his model of pitch class space meets his five conditions mentioned above; in particular, that "quantified distances tally with the empirical evidence."[93]

Root:	*a*	C											
Fifth:	*b*	C							G				
Triad:	*c*	C				E			G				
Diatonic:	*d*	C		D		E	F		G		A		B
Chromatic:	*e*	C	$C^{\#}$	D	$D^{\#}$	E	F	$F^{\#}$	G	$G^{\#}$	A	$A^{\#}$	B
		$B^{\#}$	D^{b}		E^{b}	F^{b}	$E^{\#}$	G^{b}		A^{b}		Bb	C^{b}

Root:	*a*	0											
Fifth:	*b*	0							7				
Triad:	*c*	0				4			7				
Diatonic:	*d*	0		2		4	5		7		9		11
Chromatic:	*e*	0	1	2	3	4	5	6	7	8	9	10	11

Figure 1.3. Lerdahl's pitch class space in letter names and pitch classes showing I/**C**.

The vertical distance is calculated by counting the number of vertical steps from level *a* to the first appearance of the pitch class of interest. A lower number indicates more tonal stability (in a particular context) than does a higher number. Thus, in the context of I/**C**, $C^{\#}$ (or pc2) has a vertical depth of embedding of 4.[94] In the context of I/**A**, the vertical depth of embedding of $C^{\#}$ is now 2 indicating this pitch class is more stable in the context of A major than it is in the context of C major.[95] Lerdahl reports listeners experienced in tonal music are likely to agree with this assessment.[96]

Distance along the horizontal also is measured in the number of steps. Measurement is taken from the first occurrence of a pitch class. A step is defined as the movement from one pitch class to the next horizontally adjacent pitch class at any level. Thus, in the context of C major, moving from G to E at level *c* is a step,[97] as is movement from G to C at level *b*, and G to A^{b} at level *e*. Lerdahl believes these values are cognitively equal although the

[93] Lerdahl (2001), 48.
[94] Beginning with level *e* (where $C^{\#}$ first appears) and moving to level *d* adds a count of 1, moving to level *c* adds another count of 1, moving to level *b* adds another count of 1, and moving to level *a* adds another count of 1, totalling 4. The result is the same if you begin with the most stable level, level *a*, and move downwards to find the first occurrence of $C^{\#}$ at level *e*.
[95] Beginning with level *c* (where $C^{\#}$ first appears) and moving to level *b* adds a count of 1, moving to level *a* adds a count of 1, totalling 2. The result is the same if you begin with the most stable level, level *a*, and move downwards to find the first occurrence of $C^{\#}$ at level *c*.
[96] Lerdahl references research published by Carol Krumhansl to support this statement. See chapter 2 for further discussion of empirical basis of Lerdahl's model.
[97] G to E at level *d* is two steps (G→F→E) demonstrating G and E are perceived as more distant at the diatonic level than they are at the triadic level (in the context of I/**C**).

distance in semitones is not equivalent (3, 5, and 1 respectively).[98] He once again supports his claim with empirical research.

The vertical and horizontal distances can be summed, creating a combined distance representing the relative stability of a pitch class within a particular tonal context. According to Lerdahl, each pitch class within a tonal context wishes to move towards a more stable pitch class.[99] The most stable pitch class is the root of the triad. Thus E, at level *d*, wants to move a vertical step to the more stable triadic E of level *c*, at which point this E now wants to move a horizontal step to its root, the more stable C. The triadic C wants to move a vertical step to the more stable fifth C, which wants to move a vertical step to the most stable root C. The combined distance is 4. The actual number of steps given by Lerdahl is 3, because steps are counted beginning at the most stable level. Thus, the number of steps for E should begin with the E occurring at the triadic level (*c*), not the diatonic level (*d*). It moves a horizontal step to the triadic C, which moves a vertical step to the fifth C, and then another vertical step to the root C. Now the total is 3. The total of steps for F is 5 indicating it is perceived as being further from the stable root of this I/**C** triad.

By what route does F arrive at C? F is found first at the diatonic level (*d*). F could move a horizontal step to the E or to G, both of which are more stable in the context of C major. By moving first to the diatonic E, followed by the triadic E, the triadic C, the fifth C and, finally, the root C, the total number of steps would be 5. By moving to diatonic G instead, then to the triadic G, the triadic C, the fifth C, and the root C, the total number of steps is also 5.[100] The value of 5 for F indicates it is a less stable pitch class, in the context of I/**C** than is E (3). Diatonic D also has two choices. Both C and E are more stable in the context of I/**C**. Both C and E are two semitones away. To which route is D attracted? The route through diatonic E results in 5 steps, while the route through diatonic C results in 4 steps. Lerdahl states in his *Principle of the Shortest Path*, which is similar to Weber's *Principle of Simplicity,* the shortest path is cognitively efficient.[101] Due to the *Principle of the Shortest Path* and Lerdahl's theory of melodic

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[98] The distance is measured by the shortest route, i.e. E↑G (3 semitones) not E↓G (9 semitones). Shortly, Lerdahl's *Principle of the Shortest Path* will be discussed.

[99] This theory is consistent with views of Rameau, Weber, Schenker, and Kurth. Rameau writes of the major dissonance (leading tone) seeking the tonic and the minor dissonance (added seventh) seeking the pitch a semitone below. The result is the arrival at pitches of the more stable tonic triad. Similarly, Weber and Schenker describe how dissonance strives to resolve to consonance (found in the pitches of the triad). Kurth also writes of dissonance resolving to consonance. Lerdahl converts dissonance and consonance into, respectively, unstable/tension and stable/relaxation.

[100] Lerdahl's theory of melodic attraction (see p. 34), as well as Kurth's, indicates F is more strongly attracted to E (1.5) than it is to G (0.375), and therefore more likely to follow the first route, towards E, than the second, towards G.

[101] The *Principle of the Shortest Path* is critical to Lerdahl's calculations of perceived cognitive pitch space distances. On page 74 of *TPS* Lerdahl defines this principle as, "The pitch-space distance between two events is preferably calculated to the smallest value." In support of this principle, he cites a "kinship to the Gestalt principle of *Prägnanz* [preference of simple interpretations over complicated ones]… [and] the principle of least action in physics." Akin to these principles is Weber's *Principle of Simplicity* explained in Gottfried Weber's *The Theory of Musical Composition treated with a View to a Naturally Consecutive Arrangement of Topics.* Vol. 1, 3rd ed. Edited by John Bishop. Translated by James Warner. London: Messrs. Robert Cocks and Co., 1851, 333 as "[t]he ear explains to itself every combination of tones in the most simple, most natural, and most obvious manner." The commonality among these various principles is the concept of least effort or most efficient use of resources.

attraction, D is more likely to move toward diatonic C (melodic attraction = 0.5) than toward diatonic E (melodic attraction = 0.375).[102]

Pitch classes in the chromatic collection present an interesting problem. In pitch class terms, both D^b and $C^\#$ are represented by pc1. However, in a tonal context D^b and $C^\#$ are not equal. According to Lerdahl (and Kurth), D^b moves, by step, to C while $C^\#$ moves, by step, to D. In the context of I/**C**, D^b requires 5 steps to reach the root C while $C^\#$ requires 6. These differing values can be explained with Lerdahl's theory of melodic attraction, which considers depth of embedding (stability) and semitonal distances. While the semitonal distance is the same between C and D^b as it is between $C^\#$ and D, the depth of embedding is not, as C is a more stable pitch class in this context of I/**C** than is D. More will be said about this later.

The Chordal Space[103]

The second part of Lerdahl's tonal pitch space model deals with the perceived distance between chords. He initially considers chord distances within a single region. Once this method is established, he considers distances between chords in different regions. Recall, triads are found at level *c* in the basic space, with the fifth at level *b*, and the root at level *a*. The chromatic collection (level *e*) never changes in Lerdahl's model of tonal pitch space. When calculating chord proximity within a region, the diatonic collection (level *d*) does not change either. Only levels *a* to *c* are affected in this condition. The proximity between chords is based upon two familiar concepts from music theory—the diatonic circle of fifths and common tones.[104] The circle of fifths operates upon level *b* (the fifth) while the common tone factor operates upon level *a* (the root).

Recall, Lerdahl's fourth condition for a model of tonal pitch space stated only the interval cycle of the fifth should play a central role.[105] He now supports this stipulation by calling attention to the central role this cycle plays in tonal music.[106] First, root movement by fifths is central to cadential figures.[107] For evidence, Lerdahl draws upon psychoacoustic phenomena recalling the "prominence of the third partial [of the overtone series] in most pitched sounds."[108] Furthermore, the diatonic collection and its triads (Figure 1.4) are generated by applications of the circle of fifths. Lerdahl's *Chordal Circle-of-Fifths Rule* states,

> Move the pcs at levels a-c of the basic space four steps to the right (mod 7) on level d or four steps to the left.[109]

Let us use I/**C** from Figure 1.3 as our example. As prescribed by Lerdahl, we move by step beginning from C on level *d*, recalling C is the root of the triad. We step four times to the right, (C→D, D→E, E→F, F→G). G is

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[102] As discussed later, melodic attraction is inversely related to tension. Thus, a higher melodic attraction value means a lower tension value. D is more strongly attracted to C than it is to E resulting in less tension if D moves to C than if D moves to E.
[103] This space is represented by *j* in later formulae.
[104] See footnote 72 for explanation of Rameau's comments on common tone progressions.
[105] Here, I am paraphrasing Lerdahl (2001), 47.
[106] Lerdahl (2001), 54.
[107] Rameau, in *Génération Harmonique*, writes about the sense of repose experienced by hearing the descending fifth root movement of the V→I cadence. Schenker's description of the rising fifth (producing development and forward motion) and falling fifth (producing sense of return) of *Bassbechung* (I→V→I) also support Lerdahl's assertion.
[108] Lerdahl (2001), 54.
[109] Lerdahl (2001), 54.

now the root of the new triad. The C at the level of the fifth (*b*) becomes G causing the original G (of C) to change to D. The C at the root level (*a*) also becomes G (Figure 1.4).

Root:	*a*	C												
Fifth:	*b*	C							G					
Triad:	*c*	C				E			G					I/**C**
Diatonic:	*d*	C →		[1]D →		[2]E →	[3]F →		[4]G		A		B	
Chromatic:	*e*	C	$C^{\#}$	D	$D^{\#}$	E	F	$F^{\#}$	G	$G^{\#}$	A	$A^{\#}$	B	
		$B^{\#}$	D^{b}		E^{b}	F^{b}	$E^{\#}$	G^{b}		A^{b}		B^{b}	C^{b}	

Root:	*a*								G					
Fifth:	*b*			D					G					
Triad:	*c*			D					G				B	V/**C**
Diatonic:	*d*	C		D		E	F		G		A		B	
Chromatic:	*e*	C	$C^{\#}$	D	$D^{\#}$	E	F	$F^{\#}$	G	$G^{\#}$	A	$A^{\#}$	B	
		$B^{\#}$	D^{b}		E^{b}	F^{b}	$E^{\#}$	G^{b}		A^{b}		B^{b}	C^{b}	

Figure 1.4. Application of the Chordal circle-of-fifths rule from I/**C** to V/**C**.

The number of steps around the chordal circle-of-fifths (Figure 1.5) measures the distance between the two chords. I to vi is accomplished in 3 steps indicating V (1 step from I) is perceived as closer to I than is vi.[110] Lerdahl once again invokes the *Principle of the Shortest Path* as I→vi is not 4 steps to the left but 3 steps to the right.

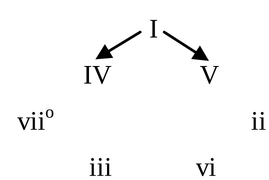

Figure 1.5. The diatonic chordal circle-of-fifths (major key), with one step to the right and one to the left, based on Lerdahl (2001), 55.[111]

As in the steps in the Basic Diatonic space, not all steps around the chordal circle-of-fifths are the same semitonal distance. Recall, a step in the chromatic level of the Basic Diatonic Space is one semitone. A step in the triad level is either 4 semitones (root to third) or 3 semitones (third to fifth). A step from I to V in the chordal circle-of-fifths is 5 semitones (applying the shortest distance rule) . A step from IV to vii^0 is 6 semitones. In the minor key, a step from iv to vii^0 is also 6 semitones while a step from equally plausible iv to VII is 5 semitones (applying the

[110] The concept of "closer" is examined below in the context of the complete theory.
[111] Lerdahl presents the chordal circle-of-fifths for Major keys but does not explain how it functions for minor keys. In minor keys it is possible to have V and v or iv and IV. These conditions do not cause problems for the chordal circle-of-fifths because V and v have the same root (as do iv and IV). Thus, i to v or i to V is still one step along the chordal circle-of-fifths. However, it is also possible to have vii^0 and VII occur in a minor key. In this case the roots of the chords are different (B and B^b, respectively, in the context of c minor). Although not clearly explained by Lerdahl, both chords would be 2 steps from i. The difference in pitch content is addressed in Lerdahl's Basic Diatonic Space. Lerdahl's figure 2.9 (p. 55) shows pitch classes as well as Roman numerals—both representing chords as they are found in the Major keys.

shortest distance rule). The differing distances are dealt with by counting the uncommon pitches in the Basic Diatonic Space.

Lerdahl's common tone factor now becomes relevant. Consider the representation of I/**C** and V/**C** in Figure 1.4. As we saw, levels *d* and *e* remain unchanged. The pitch classes at level *a* are different. One pitch class (G) is found in both chords at level *b* and two pitch classes are different at level *c*. Changes in the basic space, moving from I/**C** to V/**C**, are shown as underlined in V/**C** in Figure 1.4, and total 4. There are also 4 pitch class differences when comparing I/**C** with vi/**C** (Figure 1.6). This indicates, in a major key, V and vi are equally close to I, contradicting what we learned from applying the circle-of-fifths rule above, which indicated vi was further away (3 steps) from I than was V (1 step).

The apparent contradiction may be explained partially by recalling the basic space is hierarchical. In this instance, this means common tones at the most stable level *a* (root) are more important (or have more influence) than do common tones appearing only at less stable level *b* (fifth). In a similar manner, common tones at level *b* (fifth) have more influence than do common tones appearing only at less stable level *c* (triadic), et cetera. How is this weighting manifested? The influence is related to the number of times the uncommon pitch classes appear. Thus, they are counted at all levels. In this manner, C-E-G and G-B-D do not differ by 2 pitch classes (C and E versus B and D respectively) nor C-E-G and A-C-E by 1. Lerdahl's model of chord distance gives weight to the fact that the root is changed between I and vi by giving the root a count of 3 instead of 1.

Root:	*a*										A			vi/**C**
Fifth:	*b*					E			G		A			
Triad:	*c*	C				E			G		A			
Diatonic:	*d*	C		D		E	F		G		A		B	
Chromatic:	*e*	C	C#	D	D#	E	F	F#	G	G#	A	A#	B	
		B#	Db		Eb	Fb	E#	Gb		Ab		Bb	Cb	

Figure 1.6. Lerdahl's basic space for vi/**C**.

At the moment, the circle-of-fifths rule indicates vi (3) is further away from I than is V (1) and the common tone rule indicates they are both the same distance (4) away from I. Lerdahl's solution, to add the two numbers together, is another version of the *Chord Distance Rule*. This rule indicates the distance between two chords may be obtained by finding the shortest number of steps around the circle-of-fifths—Lerdahl calls this *j*— and adding this to the weighted number of uncommon or distinct pitch classes, which Lerdahl calls *k*. Stated formally, the *Chord Distance Rule* now says,

> $\delta(x \rightarrow y) = j + k$, where $\delta(x \rightarrow y)$ = the distance between chord x and chord y; *j* = the number of applications of the chordal circle-of-fifths rule needed to shift x into y; and *k* = the number of distinctive pcs in the basic space of y compared to the [sic] those in the basic space of x.

Thus, $\delta(I \rightarrow V) = 1 + 4 = 5$ and $\delta(I \rightarrow vi) = 3 + 4 = 7$. Lerdahl believes these results better fit our intuition—when compared with vi, we hear V as being closer to I. An application of this rule showing the perceived distance between the tonic chord and the diatonic chords supports his conclusion, as IV and V are shown to be equally close to I, iii and vi are further away from I than are IV and V, but equally distant from I, followed by the more distant ii and vii°.

Chord	I	ii	iii	IV	V	vi	vii
Distance	0	8	7	5	5	7	8

Figure 1.7. Summary of chord distances from I.[112]

Lerdahl's model does not apply only to the calculation of chord distances from the tonic. It is possible also to calculate the distance between any two chords found within the same region. The distance between ii/**C** and vi/**C** may also be determined by the above chord distance rule. In this instance, we first can determine $j = 1$ and $k = 4$. By adding the values together (5) we find, not surprisingly (as the shortest distance between the roots of each chord pair is five semitones[113]), ii and vi are as close together as are I and IV, and I and V.

Using the chord distance numbers from Figure 1.7, Lerdahl creates a representation of chordal space. This is recreated in Figure 1.8. The chords placed on the vertical axis are more closely related than are those placed on the horizontal axis. Now, not only can we see V (5) and IV (5) are the same distance from I, but also both are closer to I than are vi (7) and ii (8). One step in the vertical direction is judged closer than one step in the horizontal direct, which is closer than one diagonal step. This representation illustrates distances between all diatonic chords found in the major key. Chordal space distances are symmetrical such that the distance from I→V is equal to the distance from V→I.[114]

iii	V	vii°
vi	I	iii
ii	IV	vi

Figure 1.8. An excerpt of Lerdahl's chordal space for major keys.[115]

The rows are reminiscent of Rameau's fundamental chords formed by the direct consonances—the tonic (I), the dominant-tonic (V), and the sous-dominante (IV)—the essential harmonies of Weber, and Kurth's *Grundpfeiler* (harmonic pillars). Within a major region iii, V, and vii° may perform a dominant function, vi, I, and iii may perform a tonic function, and ii, IV, and vi may perform a subdominant function. Within a minor key, V and vii° may act as dominants, VI and i as tonics, and ii°, iv, and VI as subdominants.[116]

One of Lerdahl's stipulations states a model of tonal pitch space must be capable of portraying pitch class, chordal, and regional space in one model. We have seen how common tones and the circle-of-fifths can be applied to pitch class space to demonstrate distances in chordal space. Presently, lacking in Lerdahl's model is the ability to determine and represent distances between chords in different regions.

[112] Lerdahl (2001) Figure 2.11, 56.
[113] The number of common tones between each progression and the number of steps around the chordal circle-of-fifths is the same for these progressions.
[114] The same cannot be said for melodic attraction values, where the attraction of ^7→^8 is not the same as the attraction of ^8→^7. (See *Melodic Attraction*, pp. 33-36)
[115] Lerdahl (2001), 57.
[116] Lerdahl considers the natural minor scale as the basic scale except where V and vii° are concerned. In these cases he assumes #^7.

The Regional Space[117]

The calculation of chordal space required movement at the root, fifth, and triadic levels. Calculations in regional space require movement at the level of the diatonic collection. Consequently, Lerdahl now creates the *Regional Circle-of-Fifths Rule* stating,

> Move the pcs at level d of the basic space seven steps to the right (mod 12) on level e or seven steps to the left.[118]

In Figure 1.9a are levels *d* and *e* for C major. Lerdahl instructions, to move 7 steps to the right on level *e*, puts the tonic C (pc0) of level *d* over pc7 of level *e*. All pitch classes found in C major continue to be present after the application of this rule, except their positions as well as their functions have changed to the context of the new F major scale.[119] For example, pitch class 0 was the tonic in C major, but is now the dominant in F major (Figure 1.9b). B (pc11) is no longer part of the new scale. It has been replaced by B^b (pc10). In this manner, the F major diatonic collection is generated. Continued applications of this rule result in the generation of all the major diatonic collections.

Scale degree:	T		ST		M	SD		D		SM		LN
Level *d*:	C		D		E	F		G		A		B
Level *e*:	0	1	2	3	4	5	6	7	8	9	10	11

a)

Scale degree:	T		ST		M	SD		D		SM		LN
Level *d*:	F		G		A	Bb		C		D		E
Level *e*:	5	6	7	8	9	10	11	0	1	2	3	4

b)

Figure 1.9. a) C major diatonic collection and b) F major diatonic collection after application of *Regional Circle-of-Fifths* Rule.

Figure 1.10 summarises the regional circle-of-fifths illustrating the number of steps between each region. The *Regional Circle-of-Fifths Rule* applies to minor regions as well, where the minor regions are represented by their relative majors with whom they share a key signature. For example, two steps from region 0 (C major or a minor) is region 2 (D major or b minor) or region 10 (B^b major or g minor).

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117 This space is represented by *i* in later formulae.
118 Lerdahl (2001), 59.
119 We are familiar with the concept of tonal function as it relates to scale position. Theorists like Rameau, Weber, and Kurth among others writing about Western tonal music, make this claim. Aristoxenus, writing about the early Greek tetrachordal system and modes, talks of *dynameis* (functions) of pitches and intervals saying, “while the genus remains constant it is reasonable to suppose that the functions [*dynameis*] of the notes do too.” (Aristoxenus, *Harmonics Book II*, 49.4-6) In tonal terms, and as demonstrated in Figure 1.9, the pitch class C/**C** functions differently than does the pitch class C/**F**.

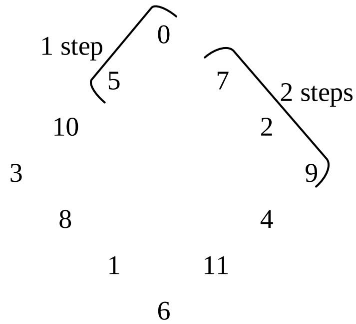

Figure 1.10. The regional circle-of-fifths.[120]

Lerdahl designates the natural minor as the representative minor scale.[121] However, the raised ^7 is included in the diatonic and triadic levels of V and vii^{o}. In Figure 1.11 are examples of the tonic and dominant chords found in d minor. Note the change at the diatonic level (*d*). The pitch classes of the natural minor make up the diatonic collection for the tonic chord. The same collection of pitch classes is found with the dominant chord except pitch class 1 ($^{\#}$^7/**d**) has been substituted for pitch class 2. The diatonic collection for V and vii^{o} in the minor keys is the harmonic minor scale.

Level *a*: 2	Level *a*: 9
Level *b*: 2 9	Level *b*: 4 9
Level *c*: 2 5 9	Level *c*: 1 4 9
Level *d*: 0 2 4 5 7 9 10	Level *d*: **1** 2 4 5 7 9 10
Level *e*: 0 1 2 3 4 5 6 7 8 9 10 11	Level *e*: 0 1 2 3 4 5 6 7 8 9 10 11
i/**d**	V/**d**

Figure 1.11. The basic space of i/**d** and V/**d** demonstrating the change at the diatonic level (*d*) compensating for the raised ^7 (pc1) when determining pcs of V and vii^{o}.

Figure 1.12 illustrates how tonal context affects the pitch class content of the basic space. Illustrated is a d minor triad in the contexts of ii/**C** and of i/**d**. Levels *a*, *b*, *c*, and *e* remain the same. It is at the diatonic level (*d*) where the effect of context is apparent. The pitch classes of the chord remain the same. It is the context of regional space, which affects *dynameis* (functions) and the pitch classes of level *d*. Thus, region must be taken into account when judging the distances between chords.

Level *a*: 2	Level *a*: 2
Level *b*: 2 9	Level *b*: 2 9
Level *c*: 2 5 9	Level *c*: 2 5 9
Level *d*: 0 2 4 5 7 9 **11**	Level *d*: 0 2 4 5 7 9 **10**
Level *e*: 0 1 2 3 4 5 6 7 8 9 10 11	Level *e*: 0 1 2 3 4 5 6 7 8 9 10 11
ii/**C**	i/**d**

Figure 1.12. Basic space of ii/**C** compared with that of i/**d**.

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[120] Based on Lerdahl (2001), 60.
[121] This is in contrast to Weber, who designates the harmonic minor as the representative minor scale.

To this end, Lerdahl formulates a new *Chordal Distance Rule*, which incorporates the context of region. Added to the previous version, which counted the pitch class differences among levels *a* to *c* (*k*) and the distance around the chordal circle-of-fifths (*j*), is the change in pitch classes at level *d* (*k*) and the number of steps around the regional circle-of-fifths (new variable *i*). The final version of the *Chord Distance Rule* states,

> $\delta(x \rightarrow y) = i + j + k$, where $\delta(x \rightarrow y)$ = the distance between chord x and chord y; *i* = the number of applications of the regional circle-of-fifths rule needed to shift the diatonic collection that supports x into the diatonic collection that supports y; *j* = the number of applications of the chordal circle-of-fifths rule needed to shift x into y; and *k* = the number of distinctive pcs in the basic space of y compared to those in the basic space of x.[122]

Taking the chords and regions of Figure 1.12 (ii/**C**→i/**d**) as an example, we can calculate the distance between them.

1. From Figure 1.10 (regional circle-of-fifths) we can determine *i* = 1, as F major, the relative minor of d is one step to the left of C major.
2. From Figure 1.5 (chordal circle-of-fifths) we can determine *j* = 0, as ii/**C** is the same chord and thus, has the same root as i/**d**, albeit, in a different tonal context (addressed in step 1—the regional circle-of-fifths).
3. From Figure 1.12 (pitch class space) we can determine *i* = 1, as the B^b (pitch class 11) occurs in the diatonic collection of d and B (pitch class 10) occurs in the diatonic collection of C.
4. Therefore, δ(ii/**C**→i/**d**) = *i* + *j* + *k* = 1 + 0 + 1 = 2.

Compare this result with the following, in which I/**C**→i/**d**. From Figure 1.3, we have the basic space of I/**C**. i/**d** is found above in Figure 1.12. Once again, variable *i* = 1 as moving to the region of d minor adds one flat compared to the region of C major.[123] Variable *j* = 2 (root of chord C + one step = root of chord G + one step = root of chord d). The bolded pitch classes below, in Figure 1.13, identifying the pitch classes found in i/**d** but not in I/**C**, furnish a *k* value of 7.

level *a*: 0	Level *a*: **2**
level *b*: 0 7	Level *b*: **2** **9**
level *c*: 0 4 7	Level *c*: **2** **5** **9**
level *d*: 0 2 4 5 7 9 11	Level *d*: 0 2 4 5 7 9 **10**
level *e*: 0 1 2 3 4 5 6 7 8 9 10 11	Level *e*: 0 1 2 3 4 5 6 7 8 9 10 11
I/**C**	i/**d**

δ(I/**C**→i/**d**) = *i* + *j* + *k* = 1 + 2 + 7 = 10.

Figure 1.13. Calculation of the perceived distance between I/**C** and i/**d**.

We can conclude, by comparing of Figure 1.12 to Figure 1.13, listeners perceive the chord progression I/**C**→i/**d** as moving a greater distance in pitch space, and embodying more tension, then the progression of

[122] Lerdahl (2001), 60.
[123] Lerdahl suggests an easy method for the finding the number of steps between two regions is to count the changes in the key signature. In our example above, we move from no sharps or flats to one flat; *i* = 1. Moving from the region of one flat to three sharps would give an *i* = 4, as would moving from the region of one flat to the region of five flats.

ii/**C**→i/**d**.[124] Lerdahl records similarly interesting comparisons in *TPS* where, for example, δ(I/**I**→V/**I**) = 5 and δ(I/**I**→I/**V**) = 7. Listeners hear the second progression as being a greater distance in pitch space than the first, demonstrating the need for incorporating the regional distance in the calculation. For without it the listeners' perception of tension for the progression I/**I**→V/**I**, would be no different from the perception of tension for the progression I/**I**→I/**V**; chords composed of the same pitch classes, but the second chord is in a different region.

For the variable *i* (region) to be included in the distance calculations, a clear change of regions must be heard. Lerdahl considers tonicisations or applied dominants to be chords within a region temporarily altered by pitch classes borrowed from another region. For example, iv/**I**, ^{b}II/**I** (Neapolitan), and the augmented sixth chords do not indicate a change in region, rather a temporary borrowing of pitch classes from another region.[125]

Thus far, we have considered only relatively closely related regions. Lerdahl and Weber consider any region one vertical, horizontal, and (in some cases) diagonal step away to be closely related. What is Lerdahl's suggestion for determining the distance traveled in tonal pitch space between less closely related regions? For these conditions, he calls upon a concept similar to that of pivot chords employed in harmony. As pivot chords are chords common to both regions, they allow for a more smooth transition between distantly related regions. "Pivot chords can be thought of as points of tonic reorientation along a regional stepwise path."[126]

Once again, the *Principle of the Shortest Path* is brought into service.[127] This means the pathway chosen between the two regions should obtain the smallest δ value. Lerdahl makes use of Weber's space (Figure 1.14) as he compares distances between a tonic and possible pivot tonics. He concludes, by moving horizontally, vertically, and diagonally around Weber's space. Thus, for I, the closest pivot regions are ii (10), iii (9), IV (7), V (7), and vi (7) but not "the diagonal steps to v, vi [or] the seventh degree, which [are] not adjacent even diagonally in regional space."[128] Lerdahl does the same for i, determining v (7), iv (7), ^{b}III (7), ^{b}VI (9), and ^{b}VII (10) to be the closest pivot regions.

B	b	D	d	F
E	e	G	g	B^{b}
A	a	C	c	E^{b}
D	d	F	f	A^{b}

Figure 1.14. An excerpt of Lerdahl's regional space, which is identical to Weber's *Chart of Regions*.

Figure 1.15 presents, graphically, for both major and minor, the shortest distances between a region and its possible pivot regions. Movement between the above pivot regions may proceed, by step, horizontally, vertically, and diagonally.

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[124] Note also, at this point in Lerdahl's formulation the perceived distance of ii/**C**→ii/**C** (or i/**d**→i/**d**) would be 0. This could change under the *Surface Tension Rule*.
[125] Recall from the discussion of the prolongational reduction its hierarchical nature in which these temporary changes in the diatonic collection are less structurally significant. As such, they would not appear in deeper layers.
[126] Lerdahl (2001), 64.
[127] See footnote 101.
[128] Lerdahl (2001), 67. The bracketed numbers represent the distance between the region of I (or i, as the case may be) and the pivot regions, where I represents any major region and i, any minor region.

iii(9)	V(7)	v(7)	^{b}VII(10)
vi(7)	**I**(0)	**i**(0)	^{b}III(7)
ii(10)	IV(7)	iv(7)	^{b}VI(9)

Figure 1.15. Pivot regions available in major and minor regions.[129]

The example at Figure 1.16 will make movement through regional pivots more clear. Let us move from I/**C** to I/**C$^{\#}$**. The shortest distance, through regional space, moves diagonally from C major to e minor, horizontally from e minor to E major, horizontally from E major to c$^{\#}$ minor, and horizontally from c$^{\#}$ minor to C$^{\#}$ major.[130] In Figure 1.16, each tonic region is bolded, placed within a box, and surrounded by their pivot-regions. Diagonal motion is permitted between regions found within the boxes. We could not move diagonally from e minor to B major (dotted arrow) because B major is not within the pivot region of e minor.

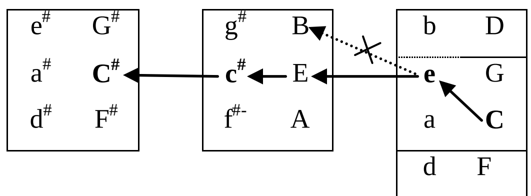

Figure 1.16. Pivot regions moving from C major to C$^{\#}$ major.

Shown below are the calculations for the distances traveled in Figure 1.16.

$$\Delta(I \rightarrow {}^{\#}I) = \delta(I \rightarrow iii = i) + \delta(i \rightarrow I = I) + \delta(I \rightarrow vi = i) + \delta(i \rightarrow I)$$

$$\Delta(C \rightarrow C^{\#}) = \delta(C \rightarrow e) + \delta(e \rightarrow E) + \delta(E \rightarrow c^{\#}) + \delta(c^{\#} \rightarrow C^{\#})$$

$$\Delta(C \rightarrow C^{\#}) = 9 + 7 + 7 + 7$$

$$\Delta(C \rightarrow C^{\#}) = 30$$

There are many other paths through pivot-regions that will take us from C major to C$^{\#}$ major, but the path above is the shortest distance. Recall, the shortest distance is considered cognitively more efficient. Taking the path C→a(7)→A(7)→f$^{\#}$(7)→c$^{\#}$(7)→C$^{\#}$(7) (= 40) allows us to arrive at the chosen region, but by traveling a longer distance. This is not to say a composer might not write a passage that follows this pathway. Lerdahl is referring to cognitive processes, not compositional processes. By following the shortest path, Lerdahl believes he is representing accurately the perceived distance between regions where a higher number represents more tension perceived than does a lower number. This new concept is summarized in his *Regional Distance Rule*, which is stated as,

> $\Delta(I \rightarrow R) = [\delta_1(P_1 \rightarrow P_2)] + [\delta_2(P_2 \rightarrow P_3)] \ldots + [\delta_n(P_n \rightarrow R)]$, where $\Delta(I \rightarrow R)$ = distance from the home pivot-region tonic I to the target region R; δ_1 = the pivot-region step from the first pivot-region tonic P_1 to the second pivot-region P_2, and so on; and $\delta_n(P_n \rightarrow R)$ = the distance from pivot-region tonic P_n to R, once R lies within the shifted pivot-region.[131]

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[129] Lerdahl (2001), 67.

[130] Diagonal movement is allowed, "if the new pivot-region tonic belongs in the first pivot region." Lerdahl (2001), 67.

[131] Lerdahl (2001), 68.

Thus, in our example above, the distance between the tonic of the C major region and the tonic of the e minor region is calculated. Next, the distance between the tonic of the e minor region and the tonic of the E major region is calculated. We continue in a like manner until we reach the tonic of the target region ($C^{\#}$ major). The distances, then, are summed.

This rule works well when moving between tonics of each pivot-region. It is equally possible, although perhaps not equally likely, to be required to move between non-tonic chords of pivot-regions. For these circumstances, Lerdahl creates the *Chord/Region Distance Rule*. Its formula is similar to the above *Regional Distance Rule* except Lerdahl generalises the chord to calculate $\Delta(C_1/R_1 \rightarrow C_2/R_2)$.[132] Measuring the distance between vi/**F** and V/**b** necessitates the use of this new rule.[133] Measuring the distance between I/**C** and I/**C#** is a special, simplified case of the *Chord/Region Distance Rule*.

Several times, we have made mention of Lerdahl's *Principle of the Shortest Path*, noted his preference for this approach, and his justification in that it is supported by cognitive science. Recall, the *Principle of the Shortest Path* simply states, "The pitch-space distance between two events is preferably calculated to the smallest value."[134] We have seen it applied in pitch class space, chordal space, regional space, and chordal/regional space.

This principle is relevant to the structures with which this discussion began. In particular, the *Principle of the Shortest Path* is applicable to the time-span and prolongational reductions. Previously, deciding which chords to reduce out and which chords are the most stable, thus proceeding to the next level, relied on "somewhat imprecise stability conditions."[135] By invoking the *Principle of the Shortest Path,* stability in terms of the time-span reduction, is determined by the distance between the chord under consideration and the local tonic. The most stable event, the event chosen to continue to the next level, is the chord with the smallest δ. Stability, in the case of the prolongational reduction is the event with the smallest distance from the regional tonic.

Stability, however, is determined by more than distances from regional tonics. Chord position and chord note in the melody also affect the listeners' perception of stability as do nonchord tones. These concerns are addressed in Lerdahl's model of hierarchical tension with the introduction of *Surface Tension Rule*.[136] Lerdahl also subsequently describes the process for determining the tonic of a particular time-span.

Tonal Tension – Sequential and Hierarchical[137]

Lerdahl believes listeners experience areas of tension and of relaxation while listening to tonal music. He proposes two models of tonal tension—sequential and hierarchical—which quantify this experience. Sequential

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[132] Begin by measuring the distance from any chord in a region to the tonic of a pivot-region that also contains the chord from the region from which we wish to depart. The calculation continues as before, measuring the distances between tonics of pivot-regions until the final distance. This situation is as we began. The final distance measured is between the tonic of the final region and the final chord (which must be in the final region).

[133] In this case, you would begin by measuring the distance (*i*, j, *k*) between vi/**F** to the tonic of another region in which D-F-A is found. From there, proceed by calculating the distance between tonics of pivot-regions. Do this until the final step—calculating the distance between i/**b** and the target chord/**region**, V/**b** (*i*, *j*, *k*).

[134] Lerdahl (2001), 74.

[135] Lerdahl (2001), 74.

[136] See p. 33 and Chapter 3 for a full description of the *Surface Tension Rule*.

[137] The sound stimuli used in the experiment described are heard outside a musical and tonal context. However, understanding hierarchical tension becomes important when determining new tension added values for Lerdahl's *Surface Tension Rule*. (See Chapter 6 and Appendix J)

tension measures the listeners' experience of the distance between consecutive chords or events. Hierarchical tension measures the listeners' experience of events connected through prolongational reduction.

In *GTTM*, Lerdahl and Jackendoff qualified areas of tension and relaxation by devising the categories of strong prolongation, weak prolongation, and progression (see Figure 1.2). Lerdahl proposes to exchange one metaphor, stability (as discussed above), with another, relaxation and instability with tension. As Lerdahl explains it, "the more unstable two events are with respect to each other, the further apart two events are in pitch space and the greater the tension that exists for one in relation to the other."[138] The most stable/relaxed event is the tonic and "tonic orientation establishes the point of stability against which the instability of other events is measured."[139] We can apply Lerdahl's tension/instability metaphor to our examples above (Figures 1.12 and 1.13) comparing δ(ii/**C**→i/**d** = 2) with that of δ(I/**C**→i/**d** = 10). From this we can conclude the progression in the latter case is more unstable, moves a greater distance in tonal pitch space, and causes the listener to experience more tension than would be experienced with the former progression.

Lerdahl's model of sequential and hierarchical tension, both of which assign numerical values to related events, also aid in assigning prolongational branchings. Used in conjunction with the metrical, grouping, time-span reduction, and prolongational reduction, the numerical values of the sequential and hierarchical tension present a detailed, although incomplete,[140] representation of the "final state of a listener's understanding."[141]

Sequential and Hierarchical Tension[142]

In his introduction to the section on sequential and hierarchical tension, Lerdahl knowingly generalises when he says naive or inexperienced listeners hear sequentially, while experienced listeners hear hierarchically. Application of the hierarchical tension rule requires an understanding of and implementation of the sequential tension rule. The models determine the cognitive distance between two chords (or events). Lerdahl defines the *Sequential Tension Rule* as:

> $T_{seq}(y) = \delta(x_{prec} \rightarrow y)$, where y = the target chord, x_{prec} = the chord immediately preceding y in the sequence (not in the reduction), $T_{seq}(y)$ = the tension associated with y, and $\delta(x_{prec} \rightarrow y)$ = the distance from x_{prec} to y (using $\delta[x \rightarrow y] = i + j + k$).[143]

This rule predicts the amount of tension experienced, by the listeners, between two consecutive events and usually applies to events occurring on the foreground (to borrow a term from Schenker) or the surface of the music.

The δ(I/**I**→V/**I**) and δ(I/**I**→I/**V**), as examples of sequential tension, pose an interesting problem.[144] How, in the context of C major, is G-B-D heard in the progression in Figure 1.17? If listeners hear it as I^6/**I**→vii^{o6}/**V**→ V/**I**→I/**I**, the predicted sequential tension value, between events 4 and 5, is 8. If listeners hear it as I^6/**I**→vii^{o6}/**V**→

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[138] Lerdahl (2001), 142.
[139] Lerdahl (2001), 142. See footnotes 179-180 and 461-464 for Rameau, Weber, Schenker, and Kurth's statements regarding the tonic as reference point.
[140] The complete model includes harmonic and melodic attraction values, and surface tension values. The complete model does not incorporate other kinds of musical tension like timbre, density, dynamics, contour, et cetera.
[141] Lerdahl (2001), 5.
[142] See Appendix N for full explanation of Lerdahl's approach to prolongation.
[143] Lerdahl (2001), 143.
[144] Using C major as our context, the letter names associated with I/**I**→V/**I** and I/**I**→I/**V** are C-E-G→G-B-D.

I/**V**→I/**I**, the predicted sequential tension value, between events 4 and 5, is 5.[145] Because we are describing sequential hearing, Lerdahl believes the listener will hear this progression as I^6/**I**→vii^{o6}/**V**→ I/**V**→I/**I** (which, he suggests, is also the shortest path and thus cognitively efficient). In sequential tension, the predicted "values convey not a tensing or relaxing in relation to a governing tonic but the tension of moving from one event to the next."[146] Thus, (according to Lerdahl and Schenker), it is only at the higher levels (layers from which less structurally significant events are removed) that G-B-D will be heard as V/**I**.

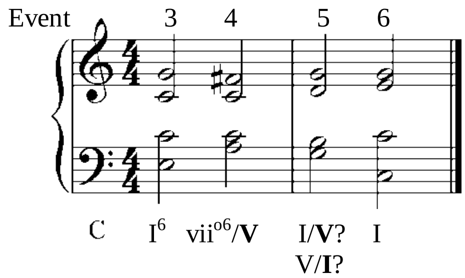

Figure 1.17. Chord progression for sequential tension calculation.

Weber's concept of *Multiple Meaning* also identifies the possibility of multiple hearings of event 5.[147] His *Principle of Inertia* states the ear, once attuned to a region, prefers to hear chords in reference to that region, unless given a sufficient cause (like a new leading tone) to reorient to a new region. This suggests the listener would hear event 5 as I/**V**. Weber, unlike Schenker, would not have proposed a change in meaning due to prolongational relationships among the events found on other layers of structural reductions as Weber did not discuss events linked through prolongation. He, however, would have proposed the listener, upon hearing event 6, would re-evaluate event 5 and retrospectively hear it as V/**I**.

Unlike sequential tension, hierarchical tension is based upon the branchings of the prolongational tree, itself a result of, and presented in conjunction with, the prolongational reduction. The prolongational tree and reduction, with their depiction of relationships between events over time, is similar to Schenker's layers of graphic representation, also showing hierarchical relationships between events.[148] Both structures highlight and connect structurally significant events.[149]

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[145] These values were obtained by following Lerdahl's application of Rameau's contention vii^{o} be considered a rootless V^7.
[146] Lerdahl (2001), 145.
[147] Rameau discusses the possibility of multiple meaning in his discussion of *double emploi*. In the context of C major, D-F-A-C may be heard as ii with an added seventh or IV with an added sixth. Aristoxenus, in his discussion of *dynameis* says, "We shall say the same thing about the functions [*dynameis*] which the natures of the tetrachords create, for the interval from *nētē hyperbolaia* and that from *mesē* to *hypatē* are written with the same sign, and the signs do not distinguish the differences in their functions." (Aristoxenus *Harmonics Book II*, 40.4-10). Aristoxenus, of course, is not referring to Western tonal music. He is referring to a similar matter occurring between two pitches, where the distance between the pitches may be the same but they function differently. Thus one interval, as with one chord in Western tonal music, may have more than one function, depending on the context in which it is found.
[148] Lerdahl claims his method is superior to Schenker's approach. Lerdahl contends his method, unlike that of Schenker's informal approach, is rule based. Lerdahl further argues, unlike Schenker's emphasis on voice-leading features, he emphasizes rhythmic and harmonic features. Lerdahl also asserts his theory is psychologically valid. (Lerdahl, 10)
[149] With Schenker's approach, less structurally significant events are removed from the graph as we move from the foreground towards the background. Schenker uses beams, slurs, flags, and various types of notes (stemmed and

When calculating hierarchical tension, inherited tension values are added to local value of an event, arriving at a global total for that event. Tension values are inherited from all superordinate branchings. The *Hierarchical Tension Rule* states:

> $T_{loc}(y) = \delta(x_{dom} \rightarrow y)$; $T_{glob}(y) = T_{loc}(y) + T_{inh}(x_{dom})$, where y = the target chord, x_{dom} = the chord that directly dominates y in the prolongational tree; $T_{loc}(y)$ = the local tension associated with y; $\delta(x_{dom} \rightarrow y)$ = the distance from $x_{dom} \rightarrow y$ (= $i + j + k$); $T_{glob}(y)$ = the global tension associated with y; and $T_{inh}(x_{dom})$ = the sum of distance values inherited by y from chords that dominate x_{dom}.

If, for example, event 4 in Figure 1.18 is subordinate to event 5, which is subordinate to event 6, which is subordinate to event 3, event 4 inherits the local total (*i, j, k*) from event 5, plus the local total event 5 inherits from event 6, plus the local total event 6 inherits from event 3, resulting in a hierarchical global tension prediction for event 4. This explains why the chord analysis in Figure 1.18 is V/**I** and I/**V**. At the local (sequential) level, G-B-D is considered I/**V**. In the hierarchical analysis, in which its global function can be evaluated, G-B-D is considered I/**V** in relation to event 4, and V/**I** in relation to event 6. When calculating pitch space distance, both functions of event 5 must be taken into account. Thus, both δ(5→4),[150] where event 5 functions as I/**V** and δ(6→5), where event 5 functions as V/**I**, are calculated. Furthermore, δ(5→5) or δ(I/**V**→V/**I**) must be calculated. This final calculation reflects Weber and Schenker's concept of retrospective hearing.

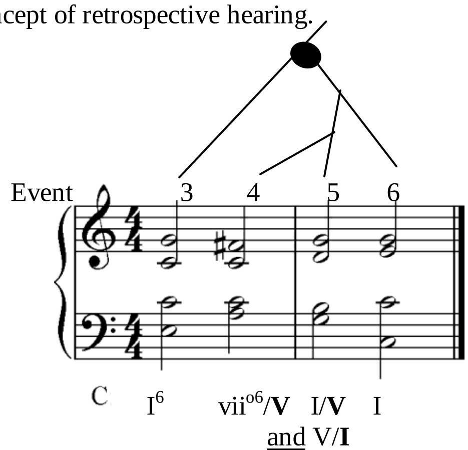

Figure 1.18. Chord progression and prolongational tree for calculation of hierarchical tension.

The following summarises the distances that must be calculated to determine the hierarchical tension values for event 4 of Figure 1.18.

1. δ(3→6)
2. δ(6→5) where event 5 = V/**I**

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stemless) to demonstrate hierarchical relationships between events. Lerdahl's approach is similar, except he adds a prolongational tree to the Schenker-like reduction layers, the branching of which depicts the hierarchical relationships between events. Lerdahl also employs different types of slurs (solid and dotted) in various combinations. These are found on the prolongational reduction in conjunction with various note values (stemmed and stemless) and portray the hierarchical relationships among events.

[150] When calculating inherited tension among left branching events, the order of events is not in temporal sequence (e.g. 5→4, 6→5). In calculating sequential tension and inherited right branching events, the order of the events is in temporal sequence (e.g. 4→5, 5→5).

3. δ(5→4) where event 5 = I/**V**
4. δ(5→5) where event 5 changes from I/**V** to V/**I**
5. The global tension value at event 4 is the sum of #1 to #4.

Step 4, δ(5→5) symbolising the calculation of the distance between two explanations of event 5, I/**V** and V/**I**, brings to mind Weber and Schenker. Weber describes how the ear continuously reevaluates chord functions as the music proceeds. He develops his *Principle of Inertia* to explain this practice as the ear "regards such combinations of tones as belonging to that key which stands in the nearest and most intimate relationship to the one to which it was previously attuned."[151] Thus, as the context changes, the ear will hear G-B-D as I/**V** or V/**I**. Schenker, like Lerdahl, portrays an event as it functions at each layer. Thus, an event may function as I/**V** at one layer and as V/**I** at another.

One chord exhibiting more than one function, as seen in Step 4 above, is not always necessary, as in the musical example in Figure 1.19. Here, the change in chord function occurs over two chords. In Figure 1.18, event 5 = I/**V** and V/**I**. In Figure 1.19 there is an extra event as, event 5 = I/**V** and new event 6 = V/**I**. It remains necessary to calculate the distance between I/**V** and V/**I**. This is, in Figure 1.19, δ(5→6), what was δ(5→5) in Figure 1.18.

Figure 1.19. Progression with extra event.

Events 5 and 6 of Figure 1.19, however, are not exactly the same as event 5 in Figure 1.18. There is, of course the difference in note values. Of more interest is the difference in the form of the chords. Both chords at event 5, in Figures 1.18 and 1.19 are, from the bass up, G-B-D-G. The chord at event 6 in Figure 1.19 is, from the bass up, G-G-D-**B**. The soprano melody note is different. Along similar lines are the chords at event 3 and event 7 in Figure 1.19. Both events are functioning as tonic chords, both with the same soprano melody note, but event 3 is in first inversion while event 7 is in root position. Lerdahl considers these, and other features, under the heading of surface tension or surface dissonance "which evaluates the psychoacoustic tension caused by surface features of an event … affected by which pitches are in the bass and which in the soprano, as well as the presence or absence of sevenths and nonharmonic tones."[152] Rameau, Weber,[153] and Schenker, in their writings, also recognize the salience of the outer voices.

[151] Weber (1851), 336.
[152] Lerdahl (2001), 150.
[153] According to Weber, "It may be remarked, in general, that the two outer parts usually make a stronger and more definite impression upon the ear than a middle part." Weber (1851), 125.

The support for the ideas asserted in Lerdahl's *Surface Tension Rule* can be found throughout the history of music theory and the writings of its theorists.[154] Commonly accepted beliefs relate to stability. A root position chord is considered more stable than is a chord in inversion. A chord with the root in the soprano is considered more stable than the same chord with another chord note in the soprano. Nonchord tones are considered less stable than chord tones. Sevenths are of special consideration as, up to this point, Lerdahl has counted them among the pitch classes at level *c* (the triadic or chordal level). He now counts them among the nonchord or nonharmonic tones. The various forms of surface dissonance are gathered together in his *Surface Tension Rule,* which states,

> $T_{diss}(y)$ = scale degree[155] (add 1) + inversion (add 2) + nonharmonic tone (add 1 for sevenths, 3 for diatonic nonharmonic tones, and 4 for chromatic nonharmonic tones), where $T_{diss}(y)$ = the surface tension associated with chord y; scale degree = chords with ^3 or ^5 in the melodic voice; inversion = chords with ^3 or ^5 in the bass; and nonharmonic tone = any pc in y's span that does not belong to y.[156]

The value for surface tension is now added to the sequential and hierarchical tension values for an event giving an overall or global tension value. The chart at Figure 1.20 summarises these parameters required for the calculation of hierarchical tension. The chart necessary for calculating sequential tension contains the same parameters but does not involve the "Inherited" and "Global Total" columns.

	Surface Tension	Pitch Space	Tension
Event	Melody + Inversion + Nonchord +	*i* + *j* + *k* +	Local + Inherited = Global

Figure 1.20. Parameters for calculating hierarchical tension.

Lerdahl's model, in predicting listeners' perception of shifting tension or instability in tonal music, measures the cognitive distances between chords. This requires measuring the distances (between pitch classes, chords, and regions), constructing hierarchical structures (metrical, grouping, time-span, prolongation), and accounting for surface dissonance. The treatises of previous music theorists, in particular Aristoxenus, Rameau, Weber, and Schenker, underpin the models of sequential tension, hierarchical tension, and surface dissonance Lerdahl establishes for tonal pitch space. Up to this point, the discussion has centred on harmony. Lerdahl next presents his theory of melodic tension. Here, we will find Lerdahl, drawing upon the writings of Kurth.[157]

Melodic Tension

A theory of melodic tension, in tonal music, cannot exist without considering harmony.[158] Lerdahl's *Melodic Attraction Rule* reflects the relationship between melody and harmony. Two factors influence listeners' experience of melodic attraction. Stability, as with harmonic tension, plays a role in melodic attraction. Lerdahl

[154] A more detailed discussion can be found in chapter 3.
[155] In chapter 3, this term is changed from Lerdahl's 'scale degree' to Melody.
[156] Lerdahl (2001), 150-151.
[157] Recall, Rameau's contention the major dissonance (leading tone) is attracted to the tonic and the minor dissonance (subdominant) is attracted to the mediant. Schenker's *Urlinie*, signifies ^4's desire to move to ^3 and ^2 to move to ^1.
[158] Recall, the term 'melody' does not refer to the soprano alone. Lerdahl's (and Kurth's) use of the term implies all horizontal lines. According to Kurth, "Just as all melody is imbued with harmonic elements, so too … *harmony* and *chords* are imbued with dynamic tensions, which determine their musical effect." (Rothfarb 1991, 45 translating Kurth's *Grundlagen des linearen Kontrapunkts: Einführung in Stil und Technik von Bach's melodishce Poyphonie*)

borrows the term "anchoring," as coined by Bharucha, where the “basis of anchoring, then, is the psychological need for an unstable pitch to be assimilated to an immediately subsequent proximate and stable pitch, which is its cognitive reference point.”[159] The other factor is distance, measured in semitones, between two melody notes. In chordal space, the distance from I to V is the same as the distance from V to I. We will discover, in melody, this is not necessarily true. The perceived distance from B to C is not necessarily the same as the perceived distance from C to B.[160]

The Melodic Attraction Rule[161]

Lerdahl returns to the basic space (Figure 1.3), this time with a modification. Level *b*, the level of the fifth, is removed in the calculation of melodic attraction. According to Lerdahl, the “calculations work out better if the fifth level, necessary for harmonic and regional modeling, is suppressed for melodic modeling; this places ^3 and ^5 at the same level.”[162] The pitch class at the root level is the most stable, followed in, succession with decreasing stability, by the pitch classes of the triad, of the diatonic collection, and of the chromatic collection. Figure 1.21 illustrates this new space, with the addition of anchoring strength, and depth of embedding. According to Lerdahl, actual pitch names are used in this instance rather than pitch classes, and a complete octave is represented because he is concerned with melody.

Depth of Embedding ↓														Anchoring Strength ↑
0	C												C	4
1	C				E			G					C	3
2	C		D		E	F		G		A		B	C	2
3	C	$C^{\#}$	D	$D^{\#}$	E	F	$F^{\#}$	G	$G^{\#}$	A	$A^{\#}$	B	C	1

Figure 1.21. Basic melodic attraction space with depth of embedding and anchoring strength of I/**C**.

As the depth of embedding (and tension) increase, the anchoring strength (and stability) decrease. Once again, the root is the most stable pitch. It is the least embedded, and has the greatest anchoring strength, thus the root most strongly attracts other pitches. Contrast this with the chromatic collection exhibiting the greatest depth of embedding or instability and weakly anchored to its position. The pitch of the chromatic collection is more strongly attracted to a more stable pitch than is a pitch at the triadic level. The depth of embedding directly corresponds to a tension value. In the above example, E and G (both equally stable triadic pitches) have a depth of embedding equal to 1 and an anchoring strength of 3. Conversely, the $G^{\#}$, a deeply embedded, unstable, chromatic pitch, has a depth of embedding value equal to 3 and an anchoring strength of 1.

As in the model of the basic pitch class space, the depth of embedding corresponds to the occurrence of a pitch at its most stable position. Thus, depth of embedding of E corresponds to its position in the triad and not in its position as part of the diatonic or chromatic collections. Also, as in the basic pitch class space model, each unstable pitch is drawn towards its neighbouring, more stable, superordinate pitch. Triadic E is not drawn towards its equal

[159] Lerdahl (2001), 161 quoting Rosch (1975).
[160] Lerdahl (2001), 167-170 labels these phenomena attractional asymmetries.
[161] This rule is used in chapter 5 to determine melodic attraction between the highest pitches of the disruptor sequences and highest pitches of the chord stimuli used in the experiment.
[162] Lerdahl (2001), 161-162.

neighbour triadic C (or G), but towards the superordinate, more stable root C as a "given pitch tends to anchor to or be relatively attracted to a superordinate neighbor."[163] The superordinate neighbour, C, is an attractor for the subordinate neighbour, E. This movement, towards the superordinate neighbour, results in a reduction in tension. In C major, an E melody note moving to C melody note results in a reduction in perceived tension. As with all other aspects of Lerdahl's model, the strength of attraction between two pitches can be quantified. The *Melodic Attraction Rule* is based upon the relative anchoring strengths of each pitch and the number of semitones between them.[164] Lerdahl states the *Melodic Attraction Rule* as,

> $\alpha(p_1 \rightarrow p_2) = (s_2/s_1) \times (1/n^2)$, where p_1 and p_2 are pitches, with $p_1 \neq p_2$;
> $\alpha(p_1 \rightarrow p_2)$ = the attraction of p_1 to p_2; s_1 = the anchoring strength of p_1 and s_2 = the anchoring strength of p_2, in the current configuration of the basic space; and n = the number of semitone intervals between p_1 and p_2.[165]

The phrase "in the current configuration of the basic space" is an important qualification. In the context of the region of C, the pitch B is strongly attracted to the pitch C. The same is not true in the context of the region of G or many other regions one could choose.

From Figure 1.21, we can calculate the attraction of B (p_1) to C (p_2) in the context of I/**C**.

$$\alpha(p_1 \rightarrow p_2) = (s_2/s_1) \times (1/n^2)$$
$$\alpha(B \rightarrow C) = (4/2) \times (1/1^2)$$
$$\alpha(B \rightarrow C) = 2 \times 1 = 2$$

We can perform the same calculation in the context of I/**G**. In this case, the pitch B is now most stable at the triadic level with an anchoring strength of 3. The pitch C is now at the diatonic level with an anchoring strength of 2.

$$\alpha(p_1 \rightarrow p_2) = (s_2/s_1) \times (1/n^2)$$
$$\alpha(B \rightarrow C) = (2/3) \times (1/1)$$
$$\alpha(B \rightarrow C) = 0.67 \times 1 = 0.67$$

The lower strength of attraction value of 0.67 indicates pitch B is less strongly attracted to the pitch C in the context of G major than it is in the context of C major. Lerdahl's theory predicts listeners will experience a greater sense of tension as B→C in **G** than they would if they experienced the same motion in **C**.

From Lerdahl's discussion of tonicisation in the context of sequential hearing in chordal space, we know the chord of resolution following the applied dominant is heard as a local tonic. Lerdahl's approach to certain chromatic melodic inflections is similarly fashioned. He allows chromatic inflections, in certain circumstances like a sharpened ^7 in a minor key, to be considered at the diatonic level. For example, $D^{\#}$ proceeding to E, in the context of I/**C**, is

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[163] Lerdahl (2001), 162.

[164] The *Principle of the Shortest Path* is in effect here as well such that the number of semitones between C and F is 5 (counting from C upwards to F) and not 7 (counting C downwards to F). (See footnote 101 for explanation of this principle.)

[165] One limitation of Lerdahl's *Melodic Attraction Rule* is it does not allow for the calculation of attraction between two instances of the same pitch. Like the alto and tenor in Figure 1.19, it is not unusual for melody notes to repeat in successive events. Lerdahl's *Melodic Attraction Rule* cannot be applied in these circumstances as n = 0. A fraction with a denominator of zero is classified undefined. For a revision of Lerdahl's *Melodic Attraction Rule,* see Elizabeth Hellmuth Margulis, "A Model of Melodic Expectation," *Music Perception* (2005): 663-714, where she proposes incorporating expectation due to direction, proximity, and hierarchy of expectation into Lerdahl's model.

elevated, temporarily, from the chromatic level to the diatonic level. This is accompanied by a reduction in its attraction value.[166] When the inflected pitch acts as a passing tone, appoggiatura, or neighbour, the attraction of chromatic $D^{\#}$ to triadic E equals 3. When the inflected pitch acts as a temporary diatonic pitch, the attraction of the temporarily diatonic $D^{\#}$ to triadic E equals 1.5. In order of decreasing attraction (corresponding to increasing tension) are the resolutions of chromatic nonharmonic pitches with the strongest attraction/least tension, followed by leading note to tonic. The applied or temporary leading note to tonic exhibits the weakest attraction or greatest tension.

The more stable a pitch is, or the least embedded it is, the less it 'needs' to move toward a more stable pitch. Lerdahl predicts the listener will experience more tension when a relatively stable pitch moves to a more stable pitch than when a relatively unstable pitch moves towards a more stable pitch. This example highlights the relationships among the levels, where the chromatic pitches are more strongly attracted to the more stable diatonic pitches, the diatonic pitches are relatively less strongly attracted to the more stable triadic pitches, and the triadic pitches are least strongly attracted to the stable root pitch. Said in another way, the "more unstable the pitch, the more it needs to resolve"[167] resulting in a strong attraction value coupled with a weak tension value.

Lerdahl's equation for the calculation of attraction between two pitches, $\alpha(p_1 \rightarrow p_2) = (s_2/s_1) \times (1/n^2)$, underlines the effects of strength of embedding (or stability) and of the semitonal distance between two pitches. Firstly, then, the greater the semitonal distance between two pitches, the weaker the attractional forces between them and the greater the tension as $p_1 \rightarrow p_2$. Secondly, the direction of attraction is important when considering pitches of differing stability. Pitches of differing stability do not have the same anchoring strengths resulting in the inequality of the fraction and its reciprocal (i.e. $p_1 \rightarrow p_2 = 2/3$ and $p_2 \rightarrow p_1 = 3/2$).

The Harmonic Attraction Rule[168]

Lerdahl next directs his theory of melodic attraction to harmonic progressions and voice leading between the pitches of the chords as "individual pitches in a chord seek stability just as do the pitches in a melody."[169] His basic premise is the attraction of the pitches of the first chord to the pitches of the second chord, in the same melodic line, is equal to the sum of all the attractional forces of the individual voices. The *Voice-Leading Attraction Rule* states,

> $\alpha_{rvl}(C_1 \rightarrow C_2) = \alpha_{r1} + \ldots \alpha_{rn}$, where C_1 and C_2 are chords in which (at the very least) not all the pitches are identical; $\alpha_{rvl}(C_1 \rightarrow C_2)$ = the realized voice-leading attraction of C_1 to C_2;

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166 The attraction of chromatic $D^{\#} \rightarrow$triadic E is $(3/1) \times (1/1^2) = 3$. The attraction of the temporarily diatonic $D^{\#} \rightarrow$triadic E is $(3/2) \times (1/1^2) = 1.5$. If $D^{\#}$ were the leading tone in I/**E** or i/**e** instead of a chromatic inflection in I/**C**, the melodic attraction of diatonic $D^{\#} \rightarrow$root E, would be $(4/2) \times (1/1^2) = 2$.

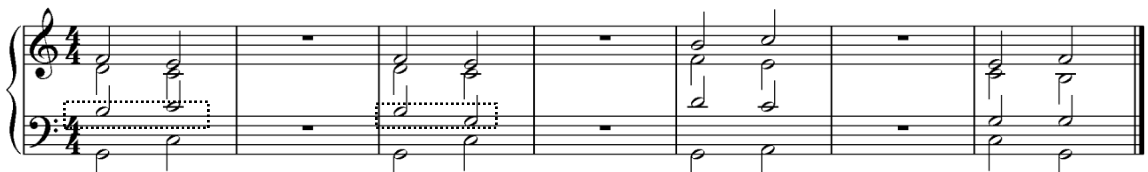
167 Lerdahl (2001), 165.

168 This rule is used in chapter 5 to determine melodic attraction between the highest (and lowest) pitches of the disruptor sequences and highest (and lowest) pitches of the chord stimuli used in the experiment.

169 Lerdahl (2001), 173. Kurth describes chords as the result of multiple melodic lines (polyphony) sounding at the same time. He believes attraction exists between pitches of a melodic line saying, "the usual explanation of melody as a 'series of tones in time' … ignores the genuine element of animation in melody" (e.g. the alto line in an four part choral composition). (Rothfarb 1991, 38 translation of Kurth's *Grundlagen des linearen Kontrapunkts*) He identifies this 'animation' as kinetic energy. Furthermore, Kurth believes in forces of attraction between the pitches among melodic lines (e.g. where the four parts sound together). He labels this force as potential energy. Lerdahl's theory of harmonic attraction examines chords in a manner similar to Kurth's theory of kinetic energy.

and $\alpha_{r1} + \ldots \alpha_{rn}$ = the sum of the realized melodic attractions for all the voices in C_1 to C_2.[170]

Consider the chord progressions in Figure 1.22. Application of the *Voice-Leading Attraction Rule* provides the values shown in bold. The progression at Figure1.22b (2.14) shows an accepted resolution of the leading tone to the dominant. The leading tone is less strongly attracted to the dominant than it is to the tonic resulting in a lower overall attraction value when compared with Figure 1.22a (4.05). One is not surprised to find, when comparing the sum of the attractional forces of Figure 1.22a (4.05) and Figure 1.22d (1.2), or Figure 1.22b (2.14) and Figure 1.22d (1.2), the pitches of V^7 are more strongly attracted to the pitches of I than the reverse, as the sense of relaxation experienced by listeners is greater for $V^7 \rightarrow I$ than for $I \rightarrow V^7$.



C: a) b) c) d)

$\alpha_{rvl}(V^7 \rightarrow I)=\mathbf{4.05}$ $\alpha_{rvl}(V^7 \rightarrow I)=\mathbf{2.14}$ $\alpha_{rvl}(V^7 \rightarrow vi)=\mathbf{4.17}$ $\alpha_{rvl}(I \rightarrow V^7)=\mathbf{1.2}$

*Figure 1.22.*Harmonic attraction values obtained through the application of Lerdahl's *Voice-leading Attraction Rule*.[171]

What does seem counter-intuitive is $V^7 \rightarrow vi$ (Figure 1.22c = 4.17) appears to be more satisfying than either versions of $V^7 \rightarrow I$ (Figure 1.22a = 4.05 and Figure 1.22b = 2.14), as a higher attraction value corresponds to a lesser sense of tension. The attraction value obtained for $V^7 \rightarrow vi$ is higher because bass G is more strongly attracted to A than it is to C.[172] Lerdahl suggests the concept of chord distance, separate from that of semitonal distance, must be included in the calculation of attraction between chords. To this end, he formulates a new rule, the *Harmonic Attraction Rule*, combining voice-leading attraction with that of chord distance, such that,

$\alpha_{rh}(C_1 \rightarrow C_2) = K[\alpha_{rvl}(C_1 \rightarrow C_2)/ = \delta(C_1 \rightarrow C_2)]$, where $\alpha_{rh}(C_1 \rightarrow C_2)$ is the realized harmonic attraction of C_1 to C_2; constant $K = 10$; $\alpha_{rvl}(C_1 \rightarrow C_2)$ is as in the voice-leading attraction rule; and $\delta(C_1 \rightarrow C_2)$ is the distance from C_1 to C_2, with $C_1 \neq C_2$.[173]

The harmonic attraction value, now, for $V_7 \rightarrow I$ (Figure 1.22a) is 8.1 and for $V^7 \rightarrow vi$ (Figure 1.22c) is 5.96.[174] These values reflect better our intuition regarding the sense of relaxation experience when hearing the two progressions, as attraction and tension values are inversely proportional—the stronger the attraction between two chords, the weaker the sense of tension (and the greater the sense of relaxation) experienced as we move from the first chord to the second chord. The pitches of V^7 are more strongly attracted to the pitches of vi than they are to the

[170] Lerdahl (2001), 173.
[171] The values shown are found in Lerdahl (2001), 174.
[172] $G \rightarrow C = (4/3) \times (1/5^2) = 0.05$; $G \rightarrow A = (2/3) \times (1/2^2) = 0.17$.
[173] Lerdahl (2001), 175. Lerdahl indicates multiplying values by the constant K is necessary because otherwise the values would be quite small and thus more difficult with which to work.
[174] $V^7 \rightarrow I = 10[4.05/5] = 8.1$ and $V^7 \rightarrow vi = 10[4.17/7] = 5.96$. Recall, the number in the denominator comes from the *chord distance rule* where the distance between two chords is $i + j + k$.

pitches of I, but V is closer (in chordal space) to I than it is to vi, resulting in a higher harmonic attraction value for V^7→I. The listener experiences V^7→I as less tense or more relaxed than V^7→vi.

Lerdahl quantifies 'less tense or more relaxed,' suggestingV^7 has an "unrealized potential"[175] of 2.14 (8.1 – 5.96) when it moves to vi instead of to I. Kurth theorises melody contains kinetic energy and chords hold potential energy. According to Kurth, the kinetic energy of melody strives forward toward a goal. The forward motion is stopped, temporarily, by harmony, creating tension as the pitches within the chords exert attractional forces upon each other. Combining Kurth with Lerdahl, we find each melodic line (in this instance, soprano, alto, tenor, and bass) striving forward, attracted to more stable and semitonally close pitches. Acting simultaneously on these same pitches is the vertical component—an attractional force binding them together in a chord.[176] Attractional forces between pitches of the horizontal melodic lines must overcome the attractional forces of the vertical chordal pitches. The pitches of V^7, when moving to the pitches of vi, do not use up all their energy. The result, for the listener, is a lesser sense of relaxation than when the pitches of V^7 move to the pitches to which they are most strongly attracted—the pitches of I.[177]

Finding the Tonic[178]

Lerdahl, like Weber, believes listeners are most likely to hear an initial single pitch as the tonic.[179] Weber supports his claim with his *Principle of Simplicity*. Lerdahl invokes the stability conditions and his *Principle of the Shortest Path* as he also concludes, "when a single note or chord sounds in isolation, the listener assumes that is it the tonic, for the shortest distance is from an event to itself."[180]

The sound stimuli in this study were Major and minor chords presented without a tonal or musical context. Measures were taken to eliminate the occurrence of tonal hierarchy between successive chords. It was expected, as Weber and Lerdahl suggest, the chords would be heard as tonics and not in relation to previously heard chords.

Conclusions

Lerdahl's model of tonal pitch space is based upon the model originally conceived by Lerdahl and Jackendoff in their 1983 *A Generative Theory of Tonal Music*. To this model, comprised of metrical structure, grouping structure, time-span reduction, prolongational reduction, and the prolongation tree structure, Lerdahl adds stability conditions allowing for a more formal approach to analysis. When discussing any aspect of his model—pitch class space, chordal space, regional space, tonic-finding, melodic attraction, harmonic attraction, et cetera—

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[175] Lerdahl (2001), 176.

[176] Lerdahl does not address, directly, the attractional forces within chord. He does not calculate and sum, for example, how strongly C is attracted to E and G, E to C and G, and G to E and C. He simply indicates the pitches at the triadic level are less strongly attracted to each other when compared with their attraction to the tonic level. His calculation of pitch class space (*k*) addresses the relative stability among the pitches of a chord but not their attraction to each other.

[177] See Appendix L for Lerdahl's *Event Governance Rule* which explains how to determine attraction between chords when there are nonchord tones and/or changes in the local tonic.

[178] See Appendix M for complete explanation of Lerdahl's Tonic Finding Rule.

[179] "It [the piece] commences with only the tone $f^{\#}$, which is accordingly equivocal; still the ear forms a pretty close conjecture that the passage will run either in $F^{\#}$-major or in $f^{\#}$-minor." Weber (1851), 383.

[180] Lerdahl (2001), 194. Weber (1851, 333) says, "in the beginning of a piece of music, when the ear is as yet unpreoccupied with any key, it should be inclined to assume as the tonic harmony any major or minor three-fold harmony that first presents itself."

Lerdahl correlates stability with the listeners' experience of relaxation and instability with the listeners' experience of tension.

Lerdahl's model is hierarchical and recursive as each event at one level is subsumed by events at the next higher level. His model, and particularly the aspect of stability and the *Shortest Distance Rule*, reflects current understanding of human cognition. Lerdahl believes he has captured many of the musical characteristics into a single model—a model in which "spatial distance equals cognitive distance"[181] and a model whose factors are empirically testable. To do so, he has combined aspects of the theories of, among others,[182] Aristoxenus, Rameau, Weber, Schenker, and Kurth. There are parallels between Lerdahl and his predecessors, and among the earlier theorists themselves.

Throughout the chapters in *Tonal Pitch Space*, Lerdahl claims a music theoretic foundation for his model. We have seen some evidence for this in the discussion above. As indicated in Table Intro.2, present-day music theorists are somewhat tepid in their support for Lerdahl's model as well as for some of his assertions. Reviewers of *TPS* from the field of music theory have several concerns. I will discuss three of the recurring ones.

Proceeding non-hierarchically, the first has to do with Lerdahl's statement, "I view music theory as a branch of cognitive science."[183] Klumpenhouwer expresses his idea of the role of music theory saying, "music theory has developed quite consciously as an arm of *Bildung*"[184] [the role of which, contrary to science, is] "to improve people morally through proper (aesthetic) enculturation."[185] He sees music theory and music perception as having different goals and answering different questions. I agree with Klumpenhouwer in that respect. As I mentioned in the introduction to this dissertation, music theory and analysis <u>can</u> be about cognition. It can also be about identifying elements of, and relationships in, the music. Lerdahl, however, certainly sees his theory of tonal pitch space as 'a branch of cognitive science.'

Klumpenhouwer goes on to state a second common criticism centring on Lerdahl's system of rules. Klumpenhouwer sees them as restricting, where "the analyst is formally irrelevant to the construction of the analysis."[186] Cohn, in his review of *TPS*, comments on Lerdahl's inconsistency in applying his own rules. "Yet, questions about systematic consistency arise for a reader who has worked through the intervening material."[187] I agree with Cohn. Lerdahl attempts to create a system that may be applied methodically to tonal music. He does create many rules (some of which are called preference rules indicating some leeway in adhering to them). Yet at times, in his own analyses, he opts for musical intuition over his own rules. London, in his review of *TPS* mentions this concern as well. He describes how Lerdahl himself is aware sometimes of the results of applying his theory to scores can lead to counterintuitive results. London says, "we witness the struggle of a researcher who sticks to his

[181] Lerdahl (2001), 46.
[182] Among the theorists Lerdahl references in support of his model of tonal pitch space are Fétis (1784-1871), Hindemith (1895-1963), de Momigny (1805-1868), Riemann (1849-1919), Schoenberg (1874-1951), and Sechter, (1788-1867).
[183] Lerdahl (2001), vii.
[184] Henry Klumpenhouwer, "Review of Tonal Pitch Space by Fred Lerdahl," *Journal of the American Musicological Society*, Vol. 58, no. 2 (2005): 489-490.
[185] Klumpenhouwer, 489.
[186] Klumpenhouwer, 490.
[187] Richard Cohn, "Review: Fred Lerdahl. *Tonal Pitch Space*," *Music Theory Spectrum*, Vol. 26, no. 1 (2007): 107.

theoretical guns without stinting his musicianship ... in *Tonal Pitch Space* we have a volume that demonstrates what can be gained when knowledge of empirical research, systematic music theory, and musical intuitions are artfully combined."[188]

Another concern is how Lerdahl's model deals with minor keys. Most of the examples of the three spaces (pitch class, chordal, and regional) are in the major key. Most of the musical examples demonstrating the application of his rules are in the major key. He does suggest how the pitch class space may be altered to reflect the natural minor saying, "I shall regard the natural minor as basic. However, for V and vii^0 the raised seventh will be assumed."[189] As we shall see in chapter 2, the Basic Diatonic Space does not reflect empirical data obtained from experiments in the minor key. The results from this present study (chapters 3 and 4) suggest Lerdahl needs to address minor chords as well.

Lerdahl's model calculates a global tension value for each event on a musical score by summing pitch space components (pitch class, chordal, regional), tension (local and inherited), and surface tension (inversion, melody, nonchord). All aspects of Lerdahl's predictive model of tension perceived by listeners with experience of tonal music rely on a musical and tonal context. All aspects, that is, except his *Surface Tension Rule*. Lerdahl proposes instability due to the psychoacoustical properties of a chord may be identified and quantified. After a review of the studies in perception Lerdahl cites in support of his model, it is this part of Lerdahl's model that is explored in the remaining chapters.

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[188] Justin London, "Review of Lerdahl's *Tonal Pitch Space*," *Music Perception*, Vol.20, no.2 (2002): 217. 203-218
[189] Lerdahl (2001), 61.

CHAPTER 2: LERDAHL'S MODEL OF TONAL PITCH SPACE AND EMPIRICAL EVIDENCE

Introduction

In Chapter 1, I introduced Lerdahl's model of tonal pitch space developed to predict listeners' experience of tension and relaxation in Western tonal music. This model consists of three interconnected spaces—pitch class, chord, and region—where spatial distance equals cognitive distance. Lerdahl believes his model is supported by empirical findings, particularly those of Carol Krumhansl and her co-workers. He cites Krumhansl's key profile as support for the stratified hierarchy of pitch classes in his Basic Diatonic Space. The harmonic or chordal hierarchy obtained by Krumhansl is cited as evidence for Lerdahl's *Chordal Distance Rule*, which quantifies perceived distances between chords. Krumhansl's correlations between key profiles of all regions, and between harmonic hierarchies of all regions, resulted in the establishment of closely and distantly related regions, which Lerdahl cites as evidence for his model of Regional Space.

However, the hierarchical order proposed by Lerdahl is not always supported by empirical data. We will see, when evidence from music perception conflicts with the generally accepted beliefs held by music theorists from Rameau forward, Lerdahl tends to choose music theory. Also, both Lerdahl and researchers in music perception tend to ignore inconsistencies between the results for the major and minor modes. Results in the minor modes tend to be within a smaller range of values and are not as consistent or as robust as are those obtained from the major mode. Research tends to be conducted in the major mode, dismissing the minor modes altogether. However, Lerdahl's model has had some success in predicting listeners' experience of tension and relaxation in some types of Western tonal music. More empirical research could lead to a more refined model.

Lerdahl outlines four goals for his model—firstly, spatial distance should equal cognitive distance; secondly, more stable elements at one level should repeat at the next higher level; thirdly, all three spaces should be incorporated into one model; and fourthly, the model should mirror empirical findings.

Spatial Distance and Cognitive Distance

Lerdahl uses Heinichen's 1728 regional circle as an example where spatial distance does not equal cognitive distance. In Heinichen's regional circle, we find major regions (represented by upper case letters) alternating with minor regions (represented by lower case letters), showing G and F majors as being equidistant from C major. Our musical intuition, supported by experimental data, would agree. However, Heinichen's regional circle also shows c minor as quite distantly related to C major. Our musical intuition and experimental results do not agree with this account. The three interconnected spaces of Lerdahl's model on the other hand attempt to portray cognitive distances as experienced by those familiar with Western tonal music. For example, his model of chordal space shows G major, F major, and c minor as equally distant from C major.

Stratified Hierarchy

More stable elements at one level of the Basic Diatonic Space, the metrical and grouping analyses, and the time-span and prolongational reductions, should repeat at the next higher level. Thus, in a specific tonal context, for example, a pitch class or chord occupying a higher level is considered more stable than pitch classes or chords at lower levels.

Single Model

All three spaces (pitch class, chordal, and regional) should be incorporated into one model. A model should be able to show the relative proximity of all the elements in each space and demonstrate the interconnectedness of the three spaces. Some previous models, like Weber's regional space or Riemann's *Tonnetz* tried to use the same representation to show relationships between pitch classes, between chords, and between regions. This is unsatisfactory as, in the context of C major, the pitch class D is heard as being in closer proximity to C than is the pitch class F. However, in the same tonal context, the chord on d is not heard as being in closer proximity to the chord on C than is the chord on F. Furthermore, the region of F major is perceived as being in closer proximity to C major than is the region of d minor. Lerdahl's model of pitch space shows the pitch class D as proximally closer to the pitch class (2 steps) C than is the pitch class F (5 steps). His model of chordal space shows, in the tonal context of C major, the d minor chord to be more distant (8) from the tonic chord than is the F major chord (5). Lerdahl's regional space shows the region of d minor to further away (10) from the region of C major than is the region of F major (7). Lerdahl's visual representation of these spaces graphically depicts these different distances between the tonic and supertonic in Pitch Class Space, Chordal Space, and Regional Space.

Empirical Findings

Lerdahl requires the model to? mirror empirical findings. There are two possible ways to satisfy this requirement. The model should predict listeners' experiences of Western tonal music, i.e., experiments should verify the model. As well, empirical findings should be employed to construct the model, i.e., experiments should inform the model. The latter is the focus of this chapter while the former is the focus of the chapter 3.

Tonal Pitch Space – the model

Pitch Class Space

In the previous chapter, we read music theory's assertion that, in Western tonal music, tonality generates hierarchy[190] among the pitch classes, among chords, and among regions. These hierarchies generate areas of stability and instability. Stability generates relaxation while instability generates tension. Lerdahl's model of the Basic Diatonic Space has five levels of varying stability. Level *a* is the octave or root level and is the most stable level. Level *b*-the fifth level contains the root and the fifth of the chord. Level *c*-the triad level includes the root, fifth, and adds the third of the chord.[191] Level *d*-the diatonic level contains all the pitch classes found in the region under consideration. Finally, level *e*-the chromatic level contains all the pitch classes found in the equal temperament tuning system. Movement from level *a* toward level *e* is accompanied by decreasing stability, increasing dissonance, and increasing tension. This Basic Diatonic Space, then, is characterised by a hierarchically organised alphabet (Lerdahl's second goal) and a spatial representation showing proximity of pitch classes (Lerdahl's third goal). Asymmetry between pitch classes, where, for example, in the context of C major, the pitch class B is heard as being closer to C than C is to B, is not represented by the Basic Diatonic Space. Lerdahl addresses this issue when calculating melodic attraction.

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[190] These relationships are termed tonal hierarchies, and are demonstrated, by current music cognition studies, as being learned, and internalised, through experiencing Western tonal music.

[191] Lerdahl considers added 7ths to be local dissonances and better dealt with in the category of surface dissonance. Chromatic chords such as augmented 6ths and Neapolitan chords are considered borrowed from other regions and treated by changes to levels *a* to *d* (root to diatonic).

Lerdahl cites Krumhansl (1979, 1983, and 1990), Krumhansl, Bharucha, and Kessler (1982), Krumhansl and Kessler (1982), and Bharucha and Krumhansl (1983) in support of his spatial representation of pitch class proximity.[192] Krumhansl and associates performed many probe tone experiments, all with a similar purpose and design. The purpose was to discover the existence and nature of the hierarchical relationships among pitch classes within a tonal context.

In the design, listeners are presented with a tonal context followed by one or two probe tones. In general, listeners are asked to judge how well the probe tone fits within the preceding tonal context. Sometimes an organ flute stop provided tones for all pitches, including those in the chords, and sometimes Shepard or circular tones were used. Unlike the organ flute stop, the Shepard tones present the listener with pitch chroma but not pitch height, alleviating concerns of shifting pitch ranges.[193] It is thought, then, with the use of circular tones, participants' sensitivity to stability and function rather than proximity is measured.

In these experiments, the most consistent and reliable data came from participants described as having a moderate level of musical experience and with little training in music theory—where, according to Krumhansl, a moderate level of musical experience means “participants have studied an instrument or instruments for five to fifteen years, have participated in performing groups for a number of years, and spend quite a bit of time listening to music. The choice of this subject population was based on a desire to obtain fairly precise and reliable data about implicit knowledge of musical structure gained through experience with music, rather than through explicit instruction in music theory.”[194] As we will see in chapters 3 and 4, level of musical expertise did not affect participants' perception of tension embodied in chords heard out of a musical and tonal context.

In Krumhansl's studies, participants were asked to rate, on a 7-point scale, how well a probe tone fit within the tonal context, where 1 = fits poorly to 7 = fits well. Krumhansl et al employed several methods to induce a tonal context—for example, with an ascending scale, with chord progressions, or with an ascending and descending scale—followed by probe tones. The listeners’ tasks were phrased differently in the various experiments as well. These include rating how similar the first tone is to the second in the given context,[195] using a 7-point scale where 1 means very dissimilar and 7 is very similar; rating how well, in a musical sense, the probe tone fits into or goes with the musical element heard,[196] where 1 means fits very poorly and 7 means fits very well; and rating how well the second tone follows the first in the context provided,[197] where 1 means follows very poorly and 7 means follows very well.

Based on the data collected when participants rated how similar the first tone is to the second in the given context, Krumhansl created a similarity matrix which reveals three levels of stability—triad, other diatonic, and nondiatonic. On average, the tones of the triad are judged most similar to each other and are considered closer to the

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[192] The Krumhansl sources are also relevant to chordal and regional proximity discussed later in this chapter.
[193] Pitch chroma is similar to pitch class in that C does not refer to a specific C (i.e., C_4 or C_5) of a specific frequency (Hz). Pitch height refers to a specific pitch and frequency (i.e., C_4).
[194] Carol Krumhansl, “Perceptual Structures for Tonal Music,” *Music Perception* 1, no. 1 (1983): 35.
[195] Carol Krumhansl, “The psychological representation of musical pitch in a tonal context,” *Cognitive Psychology* 11(1979): 346-374.
[196] Carol Krumhansl and Edward Kessler, “Tracing the dynamic changes in perceived tonal organization in a spatial representation of musical keys,” *Psychological Review* 89 (1982): 334-368.
[197] Carol Krumhansl, *Cognitive Foundations of Musical Pitch* (New York” Oxford University Press, 1990), 124.

other diatonic tones than they are to the chromatic tones. Krumhansl associates distance with stability. Thus, triad tones are more stable than are other diatonic tones, which are more stable than chromatic tones.

However, some important discrepancies may be found in the similarity matrix when considering the stability relationship between specific tones, some of which may be explained by the design of Krumhansl's experiment, i.e., the results may have been affect by pitch height as higher pitches are perceived as embodying more tension than are lower pitches. For example, in the context of C major, the similarity rating when C_5 is the first tone and G_4 is the second tone is 5.65, which is higher than the similarity rating of 5.53 when G_4 is the first tone and C_5 is the second tone. These values are indicative of asymmetry between pitch classes, as C_5 is rated as more similar to G_4 than G_4 is to C_5. This, contrary to Lerdahl's model of Basic Diatonic Space, would seem to indicate the fifth, G_4, is more stable than is the root, C_5 as less stable tones are attracted to more stable tones.

Krumhansl addresses several of the design problems of the above experiment in a later experiment. This time Shepard tones are used for all scale, chord, and probe tones. As well, several tonal context types[198] are employed and more regions are considered.[199] Finally, the question is more clearly stated asking participants to "rate how well the second tone followed the first tone in the context provided."[200] The average ratings[201] of the second tone support the triad, diatonic, and chromatic levels of Lerdahl's Basic Diatonic Space, although the average rating for intervals ending on D and E (in the context of C major) are exactly the same, suggesting equal stability. Krumhansl ignores this result saying instead, "[f]or major-key contexts, highest ratings were given to melodic intervals ending on the tonic, C. This was followed by intervals ending on G, then E, and so on."[202]

Once again, there are discrepancies between the individual results and Lerdahl's model of the Basic Diatonic Space. For example, the tonic followed by the mediant is rated lower (5.00), than when it is followed by the supertonic (5.75), perhaps suggesting the supertonic, and not the mediant, following the tonic is the more stable pitch class. These results, however, may be explained by Lerdahl's model of melodic attraction,[203] which does indeed demonstrate a greater attraction between the tonic and supertonic (.125) than between the tonic and the mediant (.047).

The best evidence for the stability and tonal hierarchy portrayed by Lerdahl's Basic Diatonic Space comes from data obtained by Krumhansl and Kessler in their 1982 single probe tone study. They declare the establishment of reliable profiles for major and minor keys as the central purpose of their experiment. This time the key defining contexts were scales[204] ascending one octave, a single triad,[205] and three 3-chord cadential figures[206] followed by a single probe tone. A greater variety of regions was used, as were circular tones for all tones. The probe tone ratings

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198 The context types were ascending and descending major and melodic minor scales and chord progressions I-IV-V-I (major regions) and i-iv-V-i (minor regions).
199 The tritone regions of C and F# majors and their parallel regions c minor and f# minor were used.
200 Krumhansl (1990), 124.
201 Krumhansl (1990), 125.
202 Krumhansl (1990), 125.
203 Melodic attraction is dependent upon stability (obtained from the depth of embedding of a pitch class in a modified Basic Diatonic Space) and proximity (in semitones) between the two pitch classes.
204 Major and harmonic minor scales were used in this experiment.
205 The triads were E Major (E-G#-B), d minor (D-F-A), F# diminished (F#-A-C), and dominant seventh on G (G-B-D-F).
206 ii, IV, and vi-V-I in the major keys and ii°, iv, and VI-V-i in the minor keys.

from the triads and the three 3-chord progressions correlated for each region. Averages obtained from the collapsed data indicated the tonic rating was higher than any other tone; nontonic scale tones were rated higher than were nondiatonic tones; and the tones of the triad more highly than the other diatonic tones (Figure 2.1). Krumhansl and Kessler report the ratings, highest to lowest, as the tonic, the notes of the tonic chord, the remaining diatonic notes, and, finally, the nondiatonic notes.[207] The results are reported slightly differently in Krumhansl 1990, where the ratings for the tones of the triad are reported separately such that the hierarchy for the major key has the tonic rated highest, followed by the dominant and then the mediant. This wording better reflects Lerdahl's Basic Diatonic Space.

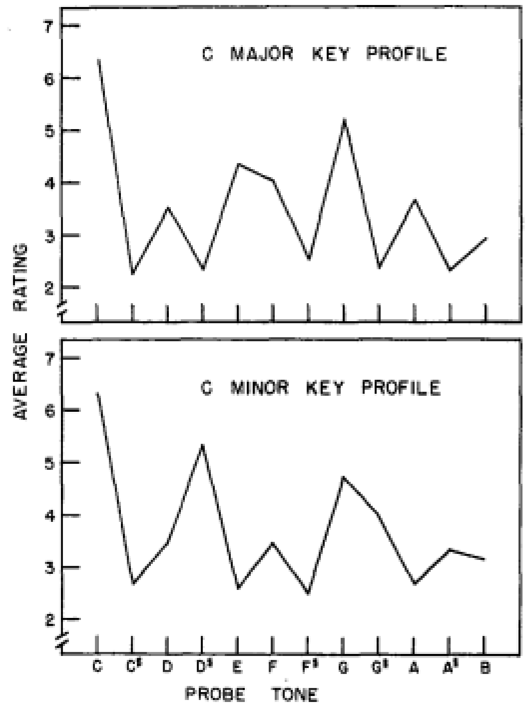

Figure 2.1. Key profile for major and minor regions. [208]

Krumhansl and Kessler found similar results for the c minor context (Figure 2.1). The profile for c minor is quite similar to that of C major with a few interesting exceptions. The highest rated, most stable pitch classes are again the tonic, dominant, and mediant but the mediant and dominant have switched order. Next, are the diatonic pitch classes, with A^b rated as better fitting than A natural, and B^b rated slightly higher than is B natural, even though the key contexts employed the pitch classes of the harmonic minor.[209] Lerdahl, aligning with the empirical data, considers the natural minor to be the diatonic collection for the minor mode, attributing the raised ^6 and ^7 to good

[207] Krumhansl and Kessler, (1982): 343.

[208] Krumhansl and Kessler, (1982), 343. The hierarchy for the tones in a major region are 1. tonic, 2. dominant, 3. mediant, 4. remaining diatonic tones (in order: subdominant, submediant, supertonic, leading tone), and 5. chromatic tones. The hierarchy for the tones in a minor region are 1. tonic, 2. mediant, 3. dominant, 4. remaining diatonic tones (in order: flat submediant, flat seventh, subdominant, leading tone, supertonic), and 5. chromatic tones (including sharp submediant).

[209] The high rating of A^b over A natural in the profile for the minor key could be due to its presentation in the chord progression. Flat ^6 is present in each of the three chords which preceded V in the chord progressions used to establish the minor key (ii^o, iv, and VI-V-i). Flat ^6 is also present in the harmonic minor scale. This does not explain the higher rating for $^{\wedge b}7$ over ^7 when it is ^7 heard in both the scale and chord contexts.

voice leading practices. The remaining nondiatonic pitch classes once again fit least well within the tonal context of c minor.

Thus, Lerdahl's Basic Diatonic Space for a major region reflects the results of Krumhansl and Kessler. However, Krumhansl and Kessler's key profile of the minor region appears to indicate the mediant (reflecting the relative major) is more stable than the dominant. This result is not mirrored in Lerdahl's Basic Diatonic Space.

Chordal Space

When considering the proximity of chords within the same region, Lerdahl makes use of the shortest distance around the Chordal Circle-of-Fifths—which becomes variable *j* in his equation—and the number of distinct pitch classes, at all levels of the Basic Diatonic Space, of the second chord with respect to the pitch classes of the first chord. This becomes variable *k* in his equation. Lerdahl reasons, the circle-of-fifths is "central because root motion by fifths is basic to cadences and pervasive at all levels of tonal organization [including] the generation of the diatonic collection and of all the diatonic triads via the fifths cycle."[210,211] By counting distinct pitch classes at all levels, Lerdahl gives weight to these differences. The weighting reflects the hierarchical position of each pitch class, within the chord, and is not dependent upon the function or stability of the pitch class within the hierarchy of the tonal context. For example, in the context of the chord D-F-A, D, as the root, is the most stable pitch of the chord, and is found at all 5 levels of the Basic Diatonic Space. In the context of C major, D-F-A is perceived as unstable. This last aspect is addressed, to some extent, by other facets of Lerdahl's model, as calculating hierarchical tension and prolongational branching, dictated by the harmonic function of the chords, incorporates tension inherited from superordinate chords by subordinate chords. The melodic attraction rule, which also relates stability to pitch class function within a tonal context, may also be applied to chords.

Analyses of data obtained by Krumhansl during several probe chord experiments demonstrate a hierarchical relationship among the diatonic chords. The results, measured in terms of chord fit within a tonal context, are illustrated on the map obtained from Multidimensional Scaling. Multidimensional Scaling transforms correlation data into a spatial representation of proximity. In this case, it is a comparison between the stabilities of probe chords in a tonal context. The closer two objects appear in the map, the closer they are perceived to be by listeners.

Krumhansl, Bharucha, and Kessler asked moderately experienced listeners to rate how well a second chord followed the first when presented within a tonal context. The tonal contexts were the ascending scales of C major, its dominant, G major, and its relative harmonic minor, a minor. Thirteen chords were used in this experiment. Some chords may be found in more than one region and, thus, with more than one chordal function. For example, the minor chord on a could be heard as vi in C major, as ii in G major, and as i in a minor. The diminished chord on g$^{\#}$ should be heard only as a triad on the raised ^7 in a minor. The minor triad on d could be heard as either ii in C major or iv in a minor. Thus, one chord may exist in one, two, or all three tonal contexts but its function, and its place in the hierarchy (represented by its 'fit' in the tonal context), will differ. Once again, circular tones were employed.

The resulting configuration of chords (Figure 2.2) around each region is slightly different. Although both are major chords, the triad on the dominant of a minor is closer to the tonic than is the dominant triad in G major.

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[210] Lerdahl (2001), 54.

[211] Both the diatonic collections of the major scale and the natural minor scale (Lerdahl's choice for diatonic level for minor regions) are obtained through a series of five Perfect fifths and one Diminished fifth.

The dominant triad is even closer to the C major tonic. The tonic G is very close to its subdominant, while C major and a minor show a greater distance to their subdominants.[212] The triad on the mediant of C major is rated as much closer than is the mediant of G major.[213] The chord on the leading tone of G major seems to be the farthest from the tonic, yet the leading tone chord is close to the a minor tonic. Triads on the supertonic and submediant also appear to be different distances in the different modes. This, however, may be due to the differences in chord quality.[214] We will see, the results of the study discussed in chapters 3 and 4 support this observation. These data from Krumhansl, Bharucha, and Kessler do demonstrate the existence of hierarchical relationships between diatonic chords and their tonic. However, they also show a difference between the hierarchies found in major and minor modes, and within major regions.

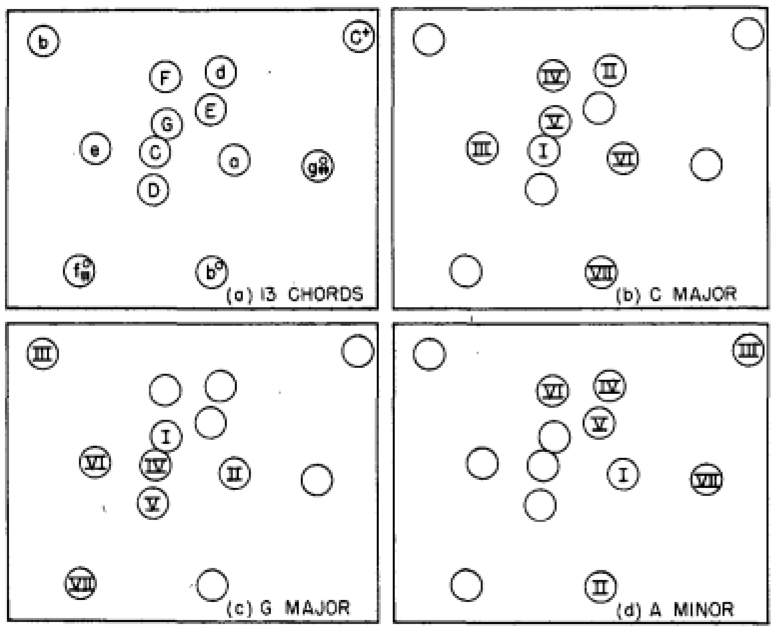

Figure 2.2. Multidimensional Scaling results showing all 13 chords around C major, G major, and a minor from Krumhansl, Bharucha, and Kessler (1982). [215]

Inconsistencies occur between the results obtained by Krumhansl, Bharucha, and Kessler, and Lerdahl's calculation of chord distances from the tonic. Perhaps the greatest discrepancy between Lerdahl's model and the results of the Multidimensional Scaling concerns the relatedness of the mediant triad to the tonic. The results of the Multidimensional Scaling suggest the mediant triad is related distantly to the tonic triad when the tonic is G (perhaps reflecting the Chordal Circle-of-Fifths relationship), but more closely related when the tonic is C (perhaps reflecting the common tone relationship). Lerdahl's model places the mediant triad in two places perhaps visually reflecting

[212] The subdominant triads for major regions are major and minor for minor regions. This may explain why the subdominant distance is different in a minor, but not why the distance is different between G and C majors.
[213] A comparison is not made between the mediant of a minor and those of C and G majors because the chord quality is different. The mediant chord in a minor is augmented while those of C and G majors are minor.
[214] The supertonic chord of a major region is minor and diminished in a minor region. The submediant chord in a minor region is major and minor in major regions.
[215] Carol Krumhansl, Jamshed Bharucha, and Edward Kessler, "Perceived harmonic structure of chords in three related musical keys," *Journal of Experimental Psychology: Human Perception and Performance* 8 (1982): 31. Because the nomenclature used, chord quality is evident in panel (a) but not in panels (b), (c), and (d).

this twofold result. However, the numerical value (7) does not change, just the visual depiction. Also, in the Multidimensional Scaling map, some of the nondiatonic chords (represented by the empty circles) were rated closer to the tonic than were some of the diatonic chords.

In another experiment, Bharucha and Krumhansl once again asked listeners with a moderate level of training to rate on a scale from 1 to 7, how well a chord fit within the tonal context. This time the tonal contexts were regions closely related (parallel major/minor) and distantly (tritone) related C and $F^{\#}$ majors, and c and $f^{\#}$ melodic minors.[216] The tonal contexts were defined by ascending and descending scales followed by one of 48 possible chords, formed from triads on all 12 chromatic scale tones, for each scale. All tones were circular tones.

Listeners also rated probe chords after a different tonal context—a chord progression based on the Circle-of-Fifths, which ensures all the diatonic pitch classes and triads are heard before the probe chord. A bias for the tonic chord still remains as, unlike other chords, it is heard twice—once at the beginning and once at the end. Krumhansl and Bharucha (1983) did a similar probe chord experiment in which the tonal contexts, C and $F^{\#}$ majors established by a IV-V-I cadence, were followed by two probe chords. Participants rated how well second chord followed the first. The results of these experiments are shown in Table 2.1.

The line labelled Krumhansl (1990) in Table 2.1 summarises the hierarchical ordering for the major regions obtained from the first two tonal contexts.[217] Listed below are Lerdahl's predicted values of distance from the tonic. Generally, there is good agreement here. The hierarchical ordering for the minor regions is shown also. This chordal hierarchy differs from that obtained in the major mode. Listed below are Lerdahl's predicted values of distance from the tonic. Again, generally there is good agreement here. However, Lerdahl's model of chordal space does not reflect the rating differences with respect to mode. The chordal hierarchy for the major mode obtained by Bharucha and Krumhansl (1983) is slightly different from that of Krumhansl (1990), and quite different from Lerdahl's values.

Although listeners' ratings for how well diatonic chords fit within a given tonal context do not follow exactly the same pattern as values obtained using Lerdahl's *Chordal Distance Rule*, it is clear a hierarchy among diatonic chords exists. Chord distance is linked to hierarchy, which is linked to stability, which is linked to tension. Lerdahl also uses the chord distance/chord hierarchy /chord stability values in conjunction with his *Principle of the Shortest Path* when creating time-span reductions and prolongational branchings.

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216 In Krumhansl, Bharucha, and Kessler (1982) the harmonic minor scale set the tonal context.

217 Ascending and descending scales and a chord progression based on the Circle-of-Fifths (I-IV-vii^{o}-iii-vi-ii-V-I and i-iv-VII-III-VI-ii^{o}-V-i) in C and $F^{\#}$ majors and c and $f^{\#}$ minors.

Table 2.1.

Comparison of chord hierarchy between Lerdahl's calculations and Krumhansl (1990), and Bharucha and Krumhansl (1983)

Source	Hierarchy: major	Hierarchy: minor
Krumhansl (1990)[218]	I, IV, V, vi, ii, iii, vii°	i, iv, VI, V, III, ii°, vii°
Lerdahl (*j* + *k*)	0, 5, 5, 7, 8, 7, 8	0, 5, 7, 5, 7, 8, 8[220]
Bharucha & Krumhansl (1983)[219]	I, V, IV, ii, vi/vii°, iii	
Lerdahl (*j* + *k*)	0, 5, 5, 8, 7/8, 7	

Note. *j* refers to the number of steps around the chordal circle-of-fifths, and *k* refers to the number of distinct pitch classes in the second chord with respect to those of the first chord. The chord of reference in this table is the tonic chord.

Regional Space

The Western tonal system also generates a hierarchy among regions. Certain regions are perceived as being closer together than are other regions. For evidence of regional hierarchy, Lerdahl returns to Krumhansl's key profiles and the above chord hierarchies. In order to determine relatedness between regions, Krumhansl correlated the key profiles obtained by transposing, into all major and minor regions, the average ratings of all probe tones for each pitch class.

Figure 2.3 shows the correlation between the pitch class hierarchy in C major (solid line) and G major (dotted line). The pitch class G, as the dominant in C major, is lower in the hierarchy than the pitch class G as the tonic in G major. The similarity between ratings of pitch classes between the two regions is obvious when simply looking at the two key profiles. In fact, the correlation coefficient, .591, confirms our suspicions—the pitch classes in both C and G majors have similar hierarchical positions.

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[218] Krumhansl (1990), 178.
[219] Krumhansl (1990), 193.
[220] Simply changing the Basic Diatonic pitch space to reflect the higher stability of ^3 in the minor keys (changing the value of *k*) does not align Lerdahl's chordal hierarchy with Krumhansl's results. A new method of calculating *j* for minor keys must also be determined.

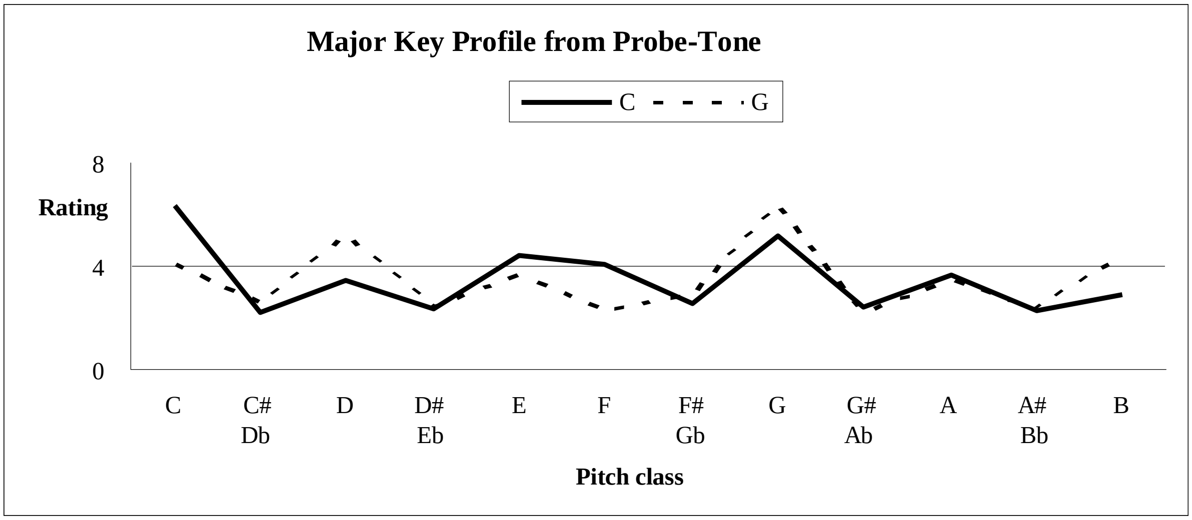

Figure 2.3. The correlation between the pitch classes hierarchy of C (solid line) and G (dotted line) majors where r = .591.[221]

We find a very different story when comparing the key profiles for C major (solid line) and F$^{\#}$ major (dotted line) in Figure 2.4. Generally, a pitch class rated high in C major is rated low in F$^{\#}$ major and vice versa. The correlation coefficient is slightly larger this time—.683—but the negative sign confirms our observation. Pitch classes rated high or more stable in one region are rated low or less stable in the other region and vice versa.

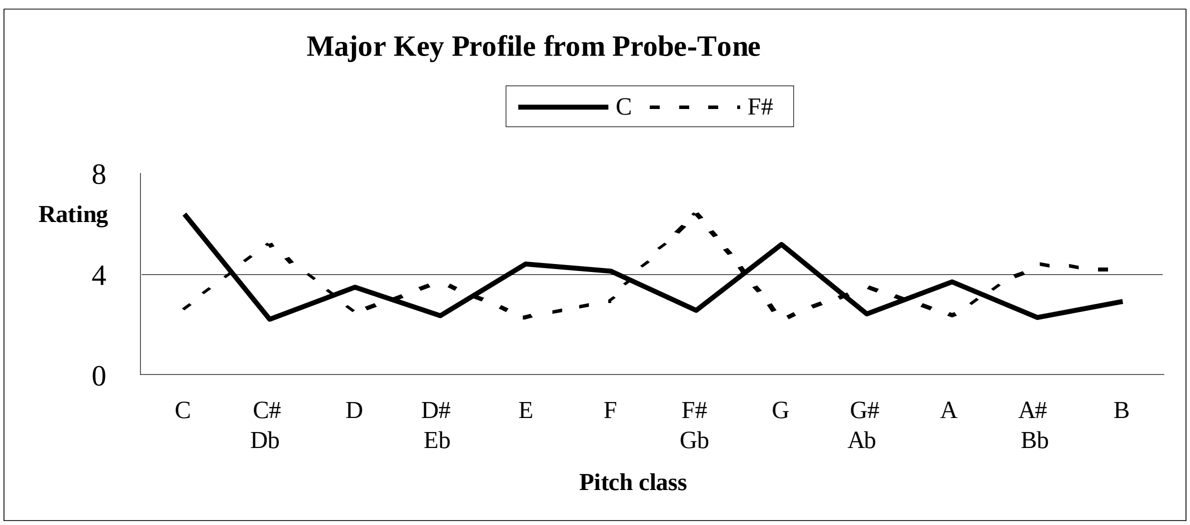

Figure 2.4. The correlation between the pitch class hierarchy of C (solid line) and F$^{\#}$ (dotted line) majors where r = .683.[222]

Table 2.2 summarises some of Krumhansl's correlation data suggesting a minor is perceived as the closest region to C major; F and G majors are perceived as equally close to C major, but slightly farther away than a minor; e minor is next closest, followed by c minor. The third column shows the calculated distances between the tonic of C major and the tonics of each region, obtained by applying the full version of Lerdahl's *Chordal Distance Rule*.

[221] The graph was created using data from Krumhansl (1990), Table 2.1, 30.
[222] The graph was created using data from Krumhansl (1990), Table 2.1, 30.

Lerdahl's Regional Space does not portray Krumhansl's correlation data precisely as an order discrepancy occurs, involving e and c minors (underlined in Table 2.2), between Lerdahl's predictions and Krumhansl's correlations. Lerdahl's Regional Space shows a and c minors as being equally close to C major. The correlation data show a minor much closer to C major than is c minor. Lerdahl's Regional Space also, contrary to the correlation data, places c minor closer to C major than it places e minor.

Table 2.2.

Comparison between Krumhansl's correlations of regions to C major and Lerdahl's calculation of distance between C major and its closely related regions[223]

Region	Pitch class Hierarchy Correlation to C Major	Lerdahl ($i + j + k$)
a	0.651	7
F	0.591	7
G	0.591	7
<u>e</u>	<u>0.536</u>	<u>9</u>
<u>c</u>	<u>0.511</u>	<u>7</u>
d	0.237	10

Note. *i* refers to the number of steps around the regional circle-of-fifths, *j* refers to the number of steps around the chordal circle-of-fifths, and *k* refers to the number of distinct pitch classes in the second chord with respect to those of the first chord. The chord of reference in this table is the tonic chord.

Table 2.3.

Comparison between Krumhansl's correlations of regions to c minor and Lerdahl's calculation of distance between c minor and its closely related regions[224]

Region	Pitch class Hierarchy Correlation to c minor	Lerdahl ($i + j + k$)
E^b	0.651	7
A^b	<u>0.536</u>	<u>9</u>
C	0.511	7
F	0.339	7
G	0.339	7
B^b	0.237	10

Note. *j* refers to the number of steps around the chordal circle-of-fifths, and *k* refers to the number of distinct pitch classes in the second chord with respect to those of the first chord. The chord of reference in this table is the tonic chord.

Krumhansl also correlates the average probe tone ratings of all the minor regions and all major regions with c minor. We see from Table 2.3, the relative major, E^b, has the strongest correlation with c minor. This is followed

[223] The correlation values are from Krumhansl (1990) Table 2.4, 38.
[224] The correlation values are from Krumhansl (1990) Table 2.4, 38.

by A^b major. Lerdahl's calculation, however, predicts A^b major to be farther from c minor than any of the other closely related regions. Next closest, according to Krumhansl, is C Major. Finally are g minor and f minor.

Lerdahl also cites Krumhansl's correlations between chord hierarchies as further support for his depiction of Regional Space. Table 2.4 shows the six regions whose chord hierarchy most highly correlated to C major. Lerdahl's calculations seem to better represent the chord hierarchy. But two regions—e and d minors, whose correlation coefficients do not place them in the top six closely related regions—receive regional distance values of 9 and 10 respectively, placing them closer to C major than either f or g minors. A similar problem exists between Krumhansl's correlation results and Lerdahl's calculations for the regions most closely related to c minor. Lerdahl predicts A^b (9) and B^b (10) majors would be perceived as more closely related to c minor than F and G majors, a prediction not born out by Krumhansl's correlational data.

Table 2.4.

Comparison between Krumhansl's correlations of regions to C major and to c minor with Lerdahl's calculation of distance between C major and its closely related regions, and between c minor and its closely related regions

Region	Correlation to C Major	Lerdahl (*i*+*j*+k)	Region	Correlation to c minor	Lerdahl (*i*+*j*+k)
c	0.738	7	C	0.738	7
a	0.405	7	Eb	0.405	7
G	0.297	7	f	0.245	7
F	0.297	7	g	0.245	7
g	0.194	14	F	0.194	14
f	0.175	14	G	0.175	14

Note. *j* refers to the number of steps around the chordal circle-of-fifths, and *k* refers to the number of distinct pitch classes in the second chord with respect to those of the first chord. The chord of reference in this table is the tonic chord.

In summary, Krumhansl's results from correlating the pitch class hierarchy of all major and minor keys with that of C major gives the following order of relatedness: a, F and G, e, c, g, d, f. Krumhansl's results from correlating the chord hierarchy of all major and minor keys with that of C major gives this order of relatedness: c, a, F and G, g, f, e, d.[225] Lerdahl predicts the following order of relatedness: c, a, F, and G equally distant from the tonic; followed by e; d; with f, g, D, and A also equally distant from the tonic. All three instances present evidence for a hierarchy among regions. All three generally arrive at the same regions. However, the order is different with each instance. Lerdahl generally follows the results of Krumhansl's chord hierarchy correlations. When conflict arises, Lerdahl tends to follow the traditions of music theory.

Krumhansl's results from correlating the pitch class hierarchy of all major and minor keys with that of c minor give the following order of relatedness: E^b, A^b, C, f and g, F, B^b. Krumhansl's results from correlating the

[225] Regardless of mode, determining regional distances based on pitch class hierarchy show the relative region as closest, i.e. for c minor, E^b major is the closest region; for A major, $f^\#$ minor is the closest region. Regardless of mode, determining regional distances based on chord hierarchy show the parallel region to be closest, i.e., for c minor, C major is the closest region; for A major, a minor is the closest region.

chord hierarchy of all major and minor keys with that of c minor gives this order of relatedness: C, E^b, f and g, F, G, A^b, e^b. Lerdahl predicts the following order of relatedness: C, E^b, f, g; A^b; B^b. As with the major mode, all three instances present evidence for a hierarchy among regions. All three generally arrive at the same regions. However, again the order is different with each instance. Lerdahl generally follows the results of Krumhansl's chord hierarchy correlations, at least for the closely related regions. Once again, when conflict arises, Lerdahl tends to follow the traditions of music theory.

Krumhansl identifies two variables, the Circle-of-Fifths, and the parallel and relative relations, as governing the correlations between regions. These are the relationships found in Lerdahl's Regional Space as the Regional Circle-of-Fifths is on the vertical, and relative and parallel regions on the horizontal (Figure 2.5). The Regional Space illustrates closely related regions to C major and closely related regions to c minor. We can move between closely related regions with one step on the horizontal plane, one step on the vertical plane, and one step on the diagonal plane. Moving from C major directly to f minor is a diagonal move but not allowed, as f minor is not in close relation to C major. You may move from C major to f minor by way of c minor or F major. Having to move two steps indicates f minor is perceived as farther from C major than is either F major or c minor.

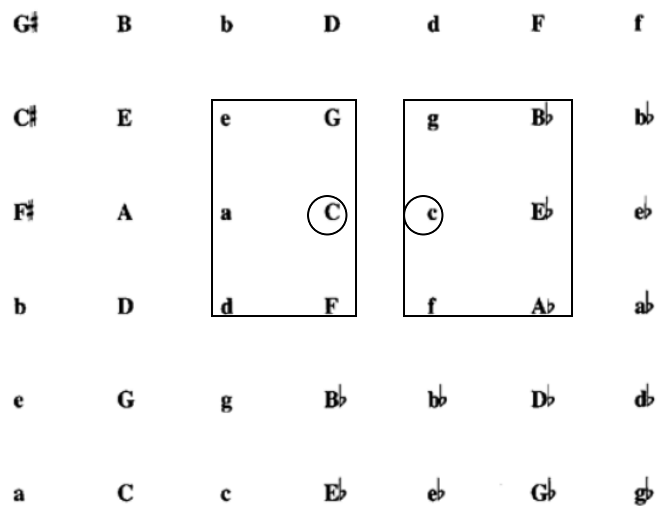

Figure 2.5. Lerdahl's Regional Space depicting the most closely related regions to C major and c minor.[226]

Lerdahl's Four Goals Revisited

The three spaces (pitch class, chordal, and regional) comprising Lerdahl's model of Tonal Pitch Space have been introduced, and the empirical data cited as support for each space of the model considered. In light of this, I now revisit the four goals Lerdahl deems necessary for an adequate model of tonal pitch space. His first goal, stating spatial distance depicted must equal cognitive distance, will be combined with the fourth goal that requires the model to mirror empirical findings.

Pitch Class Space

Beginning, then, with Pitch Class Space, Krumhansl's similarity matrices demonstrate asymmetry between pitch classes. Asymmetrical attraction between pitch classes is not depicted by Lerdahl's Basic Diatonic Space. It is addressed in his equation for determining the melodic attraction between two pitch classes where the influence of

[226] Lerdahl (2001), 64. The first three regions going down the first column are incorrectly identified as major regions. Instead of $G^\#$, $C^\#$, and $F^\#$, the regions should be $g^\#$, $c^\#$, and $f^\#$ indicating minor rather than major regions.

stability, in the form of depth of embedding, is incorporated. Krumhansl's data supports Lerdahl's concept of a pitch class hierarchy—root, triad, diatonic, and chromatic. Lerdahl adds a level of hierarchy, that of the fifth. However, Krumhansl's probe tone data demonstrate the mediant is perceived as more stable than is the dominant in the minor mode. Lerdahl's Basic Diatonic Space places the dominant at a higher level of stability than it does the mediant, regardless of mode.

Chordal Space

With respect to Chordal Space, Krumhansl's probe chord data supports Lerdahl's concept of a chordal hierarchy. Unfortunately, the chord hierarchies resulting from experiments are not consistent and do not reflect reliably Lerdahl's predictions. Furthermore, the chord hierarchy when considering all chords is not the same as when considering only diatonic chords as some chromatic chords rate higher than diatonic chords. Krumhansl suggests this may be due to an effect of chord quality such that major chords, for example, are generally rated higher than minor or diminished chords.

Regional Space

Krumhansl demonstrates the hierarchy of the constituent pitch classes of a chord influence listeners' ratings of fit within a tonal context. Lerdahl makes use of this information by giving greater weight to chord tones in the Basic Diatonic Space. This is accomplished by the repetition of chord pitch classes at several levels of this space. Krumhansl's probe tone studies demonstrate distance around the Circle-of-Fifths is associated inversely with ratings of relatedness between two pitch classes. Lerdahl incorporates distance around the Circle-of-Fifths in his calculations of perceived distances in Chordal and Regional Spaces. While an order difference (reflecting perceived relatedness of regions) exists, there is general agreement, regarding the most closely related regions, between Lerdahl's model of regional space and the correlation data of Krumhansl's pitch class hierarchies and chord hierarchies.

Second Goal

Lerdahl's second goal states the representation of pitch space is a stratified hierarchy where more stable elements at one level repeat at the next higher level. For evidence of this, Lerdahl turns also to the work of Diana Deutsch. He suggests Deutsch's experiments demonstrate listeners, when hearing melodies, extract structurally significant pitches, and create a hierarchy. Deutsch's results suggest chromatic, diatonic, and triad levels. To this, Lerdahl adds two levels—the fifth and the root. However, Deutsch's experiments probably reflect more about temporal segmentation than about stratified hierarchy. [227]

In another series of experiments, the data of Deutsch and Feroe allow for the creation of a model where stability is related to higher structural levels such that the most stable element at one level is repeated at the next higher level. Lerdahl incorporates this idea into his Basic Diatonic Space.[228] Krumhansl demonstrates, with the key

[227] In two related experiments, Deutsch asked participants to recall in musical notation 12-note melodic sequences. Deutsch describes four of the sequences as 'structured' and four as 'unstructured.' A 'structured' melodic sequence is defined as consisting "of a higher level subsequence of four elements that act on a lower level subsequence of three elements." (Deutsch 1980, 383) 'Unstructured' melodic sequences contain the same pitches as the 'structured' melodies but not the easily identifiable subsequences.

[228] Deutsch and Feroe (1981) propose a model of hierarchically embedded pitch alphabets with some similarities and some differences to Lerdahl's Basic Diatonic Space. Lerdahl's model has five distinct and different levels—root, fifth, triad, diatonic, and chromatic. Deutsch and Feroe are concerned primarily with the chromatic, diatonic, and triad levels. Lerdahl's model emphasises the generating role of the root and, more importantly, its prominent

profiles, a hierarchy among pitch classes within a tonal context, and differentiates four levels of stability—moving from least stable to most stable—chromatic, diatonic, triad, and root to which, as previously stated, Lerdahl adds another level, level *b*—the fifth of the chord.

Third Goal

Lerdahl's final goal is that the three levels of pitch space—pitch class, chord, and region—must be incorporated into one model, representing relative proximity and interconnectedness of the levels. The perceived proximity of regions is depicted in Figure 2.6—a section of Lerdahl's Regional Space from which we will take yet a smaller piece (indicated in bold).

B	**B**	**D**	**d**	F	f
E	**E**	**G**	**g**	B^{b}	b^{b}
A	**A**	**C**	**c**	E^{b}	e^{b}
D	D	F	f	A^{b}	a^{b}

Figure 2.6. A section of Lerdahl's Regional Space.

We can generate the overlapping Chordal Spaces for C and G majors. Lerdahl's Chordal Space depicts the proximity of chords to the tonic and to each other. Proximity of regions is evident from the overlap of chords between regions.

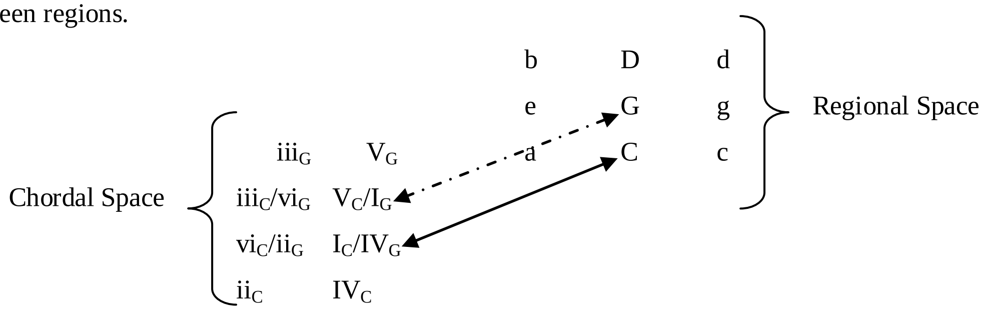

Figure 2.7. A section of Lerdahl's Regional Space and the Chordal Spaces of C and G majors.

Figure 2.8 illustrates the interconnectedness of Regional, Chordal, and Pitch Class spaces for the chord progression ii/**C** to V/**C**.

stability among the pitches of the chord. He also includes a level for the fifth of the chord as he considers it more stable than the third of the chord.

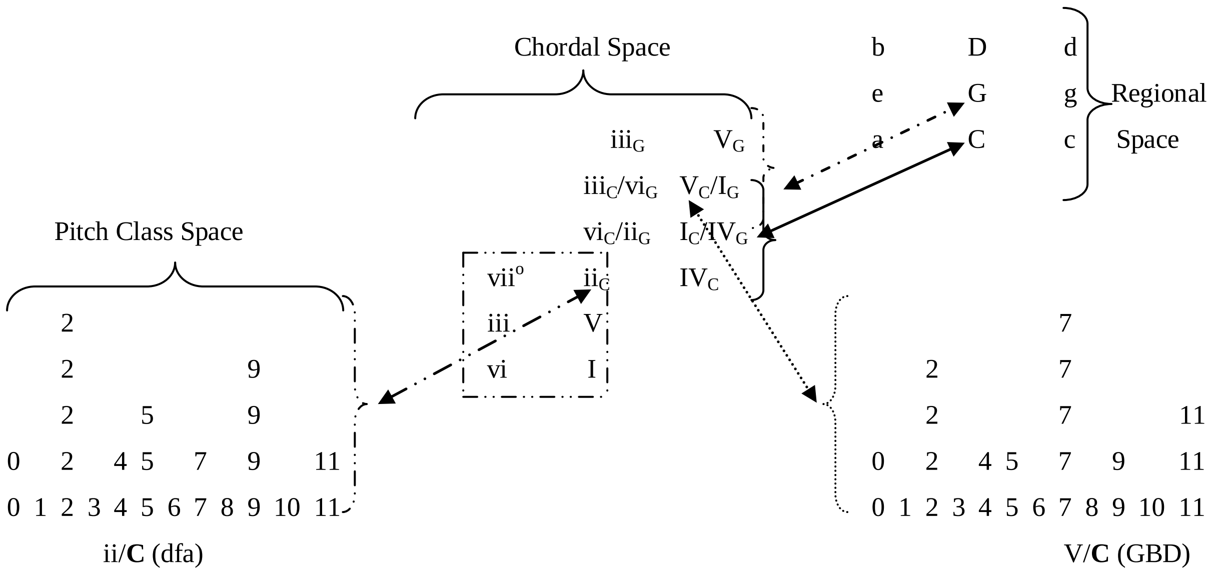

Figure 2.8. A section of Lerdahl's Regional Space, Chordal Space around C major, and Pitch Class Space of ii/**C** and V/**C**.

Beginning with Pitch Class Space, Lerdahl's model indicates both chords (ii and V) are found in the same region as level *d* (diatonic collection) is the same for both chords. We can ascertain the chords have one pitch class (2) in common. However, its stability (represented by the number of times the pitch class is present) is different for each chord. It is evident the chords are perceived as being close in Chordal Space as one application of the *Chordal Circle-of-Fifths Rule* to the first chord (ii) results in the second chord (V).[229] The Chordal Space reinforces the observation that both chords are found in the same region. If we extend the Chordal Space to include chords perceived as being close to ii (enclosed in the square), we can once again determine ii and V are close in Chordal Space as they are one step along the *Chordal Circle-of-Fifths* (represented by the vertical dimension). Linking Chordal Space around C and G majors with a small section of Regional Space, and recalling the results of Krumhansl's Multidimensional Scaling, we know ii is found only in C. On the other hand, GBD may be heard as V/**C** or I/**G**.

Using the interconnected spaces of Figure 2.8, we can calculate the perceived distance ($i + j + k$) for the chord progression ii/**C** to V/**C**. As both chords are in the same Regional Space, the value of i is 0. We can determine, from Chordal Space, the distance between ii and V around the Chordal Circle-of-Fifths is 1 step, meaning the value of j is 1. Finally, the Basic Diatonic Space indicates the number of distinct pitch classes found in V and not in ii, giving a value of 4 for k. The distance in Pitch Space between ii/**C** and V/**C** is 5. We know from the distances between the tonic chord of C major and its diatonic chords (Figure 1.7), a pitch space distance of 5 means the chords are perceived as being close together. Thus, the progression of ii/**C** to V/**C** (with a value of 5) would be perceived as less tense than the progression of ii/**C** to I/**C** (with a value of 8). This number can now be combined with surface dissonance, melodic attraction, and inherited tension to arrive at a global total tension value for this progression as it

[229] Four steps, on level *d* (diatonic), to the right from the root of ii, d, results in the root of V, G. This is one application of the chordal circle-of-fifths rule indicating V is perceived as being relatively close in Chordal Space to ii.

appears in a tonal, musical context. Lerdahl's fourth goal has been met as all three spaces may be incorporated into one model, which represents the relative proximity and interconnectedness of the levels.

Conclusions

Lerdahl developed a model demonstrating relationships among pitch classes, chords, and regions as they operate in the tonal system of Western music with the intent of predicting knowledgeable listeners' experience of this music. He bases the model on principles of music theory, which he supports with empirical data from experiments in music perception (primarily those by Krumhansl et al). Lerdahl, however, tends to side with music theory when tenets of music theory conflict with empirical evidence from music perception. This is particularly evident in Lerdahl's application of Krumhansl's data regarding chord and regional distances. We saw, in Figure 2.2 and Table 2.5, Krumhansl's chordal distance data were not consistent, nor did Lerdahl's calculations ($i + j$) match any of Krumhansl's results. Krumhansl obtained distances in regional space by correlating pitch class (key profile) data and by correlating chord hierarchy (Tables 2.2, 2.3, and 2.4). These correlations did not arrive at the same regional distances and Lerdahl's regional distances ($i + j + k$) were different again.

There has been considerable discussion around the experiments conducted by Krumhansl et al centring around three main points. The first concerns how the various tonal contexts were achieved and how that may have affected the results. The second concern has to do with the claim that listeners familiar with Western tonal music develop a schema of tonality. Finally, does "goodness-of-fit" (the question posed in Krumhansl's experiments) translate into stability (as Lerdahl suggests)?

How does one establish a tonal context without creating a bias? Weber, Schenker, and Lerdahl (in chapter 1) suggest listeners familiar with Western tonal music need only hear a single chord (or note) to identify the root of the chord (or the note) as the tonic. Indeed, this is what Krumhansl and Kessler found in one of their probe tone experiments.[230] But, could the results be due to participants' familiarity with notes of the tonic chord? For example, within the context of the E major triad (E-G$^{\#}$-B), are participants not more likely to rate a G$^{\#}$ probe tone as fitting better than any non-triadic probe tone?

The same could be said about the cadential figures Krumhansl and Kessler use to establish a tonal centre. While it is true, the chord progressions (IV-V-I, ii-V-I, vi-V-I for major keys; iv-V-i, ii^{0}-V-i, VI-V-i for minor keys) present all pitches of their respective scales (other than $^{\#}$^6 and ^{b}^7 in the minor key), the chord heard before the probe tones contains the very notes Krumhansl and Kessler found to be rated highest. It would be interesting to find how participants unfamiliar with Western tonal music rate the probe tones. If the key profile remained as Krumhansl and Kessler found with their participants, one might conclude the results were due to the presentation of the pitches of the tonic chord before the probe tones. If the key profile was different, one might conclude participants unfamiliar with Western tonal music do not possess the hierarchical tonal schema Krumhansl (and Lerdahl) believe those familiar with Western tonal music acquire through exposure to this music.

Yet, the question of Krumhansl's method for establishing a tonal centre may not be a problem for accepting Lerdahl's model. He does depend on Krumhansl's key profile to establish stability within his pitch class, chordal, and

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[230] Krumhansl and Kessler (1982). This was true when participants were presented with the Major and minor triads before probe tones.

regional spaces. However, his model assigns tension values for events heard within a tonal context, a tonal context in which the opening establishes tonality in much the same way Krumhansl did in her experiments.

I believe the second criticism of Krumhansl's experiments does not negatively impact Lerdahl's model either. Here we find two conflicting opinions. One faction believes the results are due to participants hearing the probe tones immediately after hearing the tonal context, i.e., requiring short-term memory. The other faction believes the ratings of the probe tones is due to a tonal schema possessed by those familiar with Western tonal music, i.e., involving the use of long-term memory. Once again, Lerdahl sides with Krumhansl suggesting listeners familiar with Western tonal music implicitly acquire a schema of the tonal hierarchy demonstrated by Krumhansl's experiments.

Lerdahl's sequential tension rule, describing tension perceived by "naive listeners"[231] is less affected by this debate. Tension in this case is determined by events heard temporally. Thus short-term memory may be all that is required for this type of listening. For example, if event 1 precedes event 2, tension experienced at event 2 is due to its relationship with event 1. Hierarchical tension, on the other hand, requires storing previously heard material for longer periods of time. Lerdahl's prolongational tree, where unstable events inherit tension from more stable events, is used to determine hierarchical tension. The prolongational tree is frequently nonsequential. Although there is debate concerning the length of time experienced listeners retain a single tonal centre while listening to a Western tonal piece, it is plausible to expect that experienced listeners acquire a tonal schema and thus hear hierarchically for some length of time.

Lerdahl interprets Krumhansl's goodness-of-fit results in terms of stability. Whichever pitch class, chord, or region Krumhansl found fit well within a tonal context, Lerdahl calls stable. Whichever pitch class, chord, or region Krumhansl found did not fit well within a tonal context, Lerdahl calls unstable. It is reasonable to conclude, upon presentation of a C major triad (C-E-G) in the tonal context of C major, C, E, and G would have high goodness-of-fit ratings. It is even reasonable to conclude C would be rated highest as it is the root; G rated next highest as it is the top note and thus more salient than the E, which would be rated less well fitting. If goodness-of-fit really meant fit with the triad and not fit within the key, why is B^b (2.29) rated so much lower than F (4.38) and A (3.66)?[232] One could expect B^b to receive a higher goodness-of-fit rating if participants were actually rating fit to the chord (C-E-G-B^b) rather than fit to the key of C major. For the same reason, one could expect a lower rating for F as in the context of C-E-G, F would be heard as a nonchord tone. Similarly, B (2.88), as a pitch within the key of C major, is rated higher than B^b, a pitch that could be heard as being an added seventh forming a dominant seventh chord (C-E-G-B^b). I believe, as Lerdahl does, it is reasonable to interpret goodness-of-fit in terms of stability.

What to do about the minor region is pretty much ignored by Lerdahl’s model and by empirical research. The results for the minor regions tend not to align as music theory predicts or with the results of the major regions. These differences are either not addressed or generalised. Aspects such as asymmetry are not addressed with the Pitch Class, Chordal, and Regional spaces. This is dealt with in other parts of the model such as melodic attraction and inherited tension.

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[231] "Let us assume, broadly speaking, that naive listeners stay close to the surface while experienced listeners tend to hierarchize it [music]." Lerdahl (2001), 143.
[232] For comparison, the ratings of C = 6.35, G = 5.19, and E = 4.38. Krumhansl (1990), 30.

At the same time, the model is interesting and many aspects are engaging. It is a blend of music theory and music perception creating many fascinating areas for research, which is really the other facet of Lerdahl's fourth goal, "The model should mirror empirical findings." Lerdahl created this model with the expectation that it be refined through further empirical research. Lerdahl presents empirical evidence for the aspects of his model that occur in a musical and tonal context. He does not present empirical evidence for his quantification of surface tension. This is the subject of the following chapter.

CHAPTER 3: AN EXPERIMENT TESTING ELEMENTS OF LERDAHL'S *SURFACE TENSION RULE*

Introduction

It is believed, while listening to Western tonal music, listeners experience moments of tension and relaxation brought about, in part, by musical expectations. Harmony and melody, according to music psychologist David Huron in his monograph *Sweet Anticipation* (2006), create expectations of future events. In his 2001 book, *Tonal Pitch Space*, Fred Lerdahl also draws upon this notion, and constructs prolongational structures linked to musical events on a score. Tension is quantified for each event by considering the region in which an event occurs (variable *i*), the distance between successive chords as revealed by their position on the chordal circle of fifths (variable *j*), the number of distinct pitch classes between successive chords (variable *k*), tension inherited by subordinate chords from superordinate chords, melodic attraction between successive pitches within the same melodic line, and surface dissonance. These values are added together to reveal the total or global tension experienced at an event. Each event is assigned a hierarchical position dependent upon harmonic relationships, meter, rhythm, and phrase structure.[233]

Presently, one area of Lerdahl's theory, surface dissonance, is not well supported by empirical data. Lerdahl creates categories of surface dissonance based on tenets of music theory. However, the numerical values he assigns are not necessarily compatible with the beliefs held by music theorists or the experience of listeners to Western tonal music. The purpose of the experiment described below was to obtain empirical evidence for some of the categories of surface dissonance from listeners familiar with Western tonal music. Armed with this evidence, I can make the necessary modifications to the numerical values Lerdahl assigned the elements that he believes contribute to listeners' experience of surface dissonance.

Like all components of Lerdahl's theory, surface dissonance and surface tension are linked to stability as unstable pitches are drawn toward the closest, more stable pitch.[234] Unstable tones generate surface dissonance, which generates surface tension. The amount of surface tension generated by a pitch, like chordal and regional tension, is dependent upon its place in the Basic Diatonic Space. This is explained more fully below as each category of surface dissonance is presented.

Evidence from Music Theory and Music Perception

According to Lerdahl, the surface tension factor "evaluates the psychoacoustic tension caused by surface features of an event."[235] Lerdahl specifies three categories of surface dissonance—scale degree[236] (of the soprano note), chord inversion (involving the bass note), and nonharmonic tones (in all voices and includes sevenths). The amount of added tension varies with each category and with each element within a category.

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[233] Lerdahl created rules to assist in assigning hierarchical positions to musical events. These include prolongation good form, tonic-finding rule, stability conditions, function rule, and time-span stability.
[234] Bharucha (1984a) termed this tendency "anchoring."
[235] Lerdahl (2001), 150.
[236] Lerdahl's term is scale degree but the category really refers to the position of the soprano note (root, third, or fifth) within the triad governing an event.

Scale Degree

In this category Lerdahl adds a tension value of one if either the third or fifth of a triad is found in the soprano melody[237] as "[m]elodic notes on ^3 or ^5 [of a triad] are tenser than melodic notes on ^1 [of a triad]."[238] The root of a triad is found at level *a* of the Basic Diatonic Space, the most stable level. The fifth of a triad is found at the less stable level *b*—the fifth—and the third at the even less stable level *c*—the triad. This, contrary to the tension added values in Lerdahl's *Surface Tension Rule*, would lead one to expect more added tension when the less stable third is in the melody then when the melody tone is the more stable fifth.[239]

Assigning the same tension value for when the third or the fifth of the triad are in the melody is somewhat contrary to music theory also. Rules of harmony, most likely stemming from rules of species counterpoint, indicate a melody should begin and end preferably on the tonic, sometimes on the dominant, and rarely on the mediant. When discussing counterpoint, Schenker links perfect (unison, octave, fifth) and imperfect (third and sixth) consonances with repose and motion respectively. The effect of beginning on perfect consonances is to "express the tonic … with the maximum of repose and security." [240] "In the main body [of the counterpoint], more imperfect consonances should be used than perfect … [as the imperfect consonances] foster mobility [better] than the perfect consonances."[241] Schenker is suggesting an octave, or a fifth, between the bass and the soprano is more stable than is a third between those voices.

Cadwallader and Gagné agree. When explaining species counterpoint, they state, "[n]otice that the exercise begins and ends with perfect intervals … these intervals embody maximum stability and repose … the sense of motion of 'flow' that most persons associate with tonal music is produced in part by imperfect consonances leading to and from stable points defined by the perfect consonances … [there is a] marked difference in stability between perfect and imperfect consonances."[242]

In the context of harmony, Rameau equates the perfection (or in Lerdahl's terms, stability) of intervals to their order, and ratios, when dividing a string—"The order of origin and perfection of these consonances is determined by the order of the numbers. Thus, the octave between 1 and 2, which is generated first, is more perfect than the fifth between 2 and 3."[243] Following this line of reasoning, the ratio 4:5 necessary to obtain the third (major) would make it less perfect or less stable than either the octave or the fifth.[244]

Schenker indicates a cadence will "[offer] an inferior degree of satisfaction … as the melody [in a section of Mozart's Piano Sonata K. 330], with the reappearance of the tonic [chord] … brings merely the third instead of the root tone itself, the full close here is imperfect … No less imperfect would [be a] full close which would bring the

[237] Unless otherwise stated, "melody" refers to tones found in the soprano.
[238] Lerdahl (2001), 150.
[239] Recall, in the minor mode, listeners' perception of the third as more stable than the fifth is not reflected by Lerdahl's Basic Diatonic Space.
[240] Heinrich Schenker,*Counterpoint Book I*, ed. by John Rothgeb, trans. by John Rothgeb and Jürgen Thym (Ann Arbor, Michigan: Musicalia Press, 2001), 159.
[241] Schenker (2001), 160.
[242] Cadwallader and Gagné, 26.
[243] Rameau, 6.
[244] This argument also designates the Perfect fourth, ratio 3:4, a more perfect consonance than the major third, which is problematic for Rameau.

fifth of the tonic instead of the root tone." [245] Schenker describes the forward drive toward the stable tonic, embodied in his three fundamental lines (moving by diatonic step ^8→^1, ^5→^1, and ^3→^1), as "the cessation of all tensions and efforts … the fundamental line must lead downward until it reaches ^1. With $I^{\wedge 1}$ all tensions in a musical work cease."[246] Schenker cites the overtone series as generator allowing us to generalise stability to intervals above a root of any scale degree—"It is the overtone series that affirms that the *octave* is the most perfect interval … [a]fter the octave comes the *fifth*, somewhat less perfect … [t]he hierarchy, of valuation, of the perfect consonances, then, is as follows: (a) 1, (b) 8, (c) 5 … (d) 3."[247]

Schoenberg, like Rameau and Schenker, connects levels of consonance with place on the overtone series, defining "consonances as the closer, simpler relations to the fundamental tone, dissonances as those that are more remote, more complicated … consonances … are more nearly perfect the closer they are to the fundamental."[248] Following this reasoning, the octave is more consonant or stable than is the fifth which is more consonant/stable than the (major) third.

According to Piston, when discussing cadences, the "most conclusive arrangement, [is] with dominant and tonic chords in root position, and the tonic note in the soprano … [p]lacing the third in the soprano usually gives less feeling of finality [thus more tension] than having the tonic."[249]

Andrews and Sclater, in their examples of Perfect cadences, state "the absence of the tonic note in the melody [i.e. soprano note with the tonic chord is either ^3 or ^5] results in an *open* or non-final effect."[250, 251]

Rameau and Schoenberg's theories apply to stability of root, third, and fifth of any major or minor chord. The accounts by Piston, and Andrews and Sclater apply to stability of tones making up the tonic chord but not necessarily to tones of other chords. Some of Schenker's directives apply to the tonic chord alone while others may be applied to major and minor chords in general. All agree a melody employing the fifth of the chord is more stable or final (and thus embodying less tension) than a melody employing the third of the chord. This is contrary to Lerdahl's added tension value, which equates the fifth and the third. Rather, according to music theory, it seems advisable to equate the stability of melodies employing the root and the fifth. Note, however, many of the music theorists mentioned above are referring to chords within a musical context. Lerdahl's tension added values refer to the psychoacoustic effect determined by the structure of the chords and not their musical context.

Nevertheless, there is no direct empirical evidence to support Lerdahl's numerical values of tension added due to chord tone employed in a melody. Krumhansl (1982, 1990) found a hierarchical ordering and ranges of stability of pitch classes (key profile) within a context of Western tonal music. This hierarchy is oriented towards the

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245 Schenker (1954), 217.
246 Schenker (1977), 13. $I^{\wedge 1}$ stands for root position tonic chord with scale degree 1 (or tonic) in the soprano.
247 Schenker (2001), 124. Italics are in the original.
248 Schoenberg (1978), 21.
249 Piston, 186.
250 Andrews and Sclater, 36.
251 The Piston and Andrews and Sclater references were used for two reasons. Firstly, it was surprisingly difficult to find explicit text outlining some of the 'received knowledge' of the rules in harmony. Secondly, these were some of the text I used in my education.

tonic indicating the tonic is more stable than is the dominant, which is more stable than is the mediant, etc.[252] If presented with an E in a C major melody, we would expect it to sound less stable (creating more tension) than either G or C in the melody. This is true only if E, G, and C are chord tones. (see "Nonharmonic tones" below) Krumhansl's key profile indicates the melody tone F, in the context of C major, is less stable than C, E, and G. However, according to Lerdahl's *Surface Dissonance Rule*, melody tone F supported by IV/**C** (FAC) is the root of the chord and would be more stable than would C, the tonic, as C is the fifth of IV/**C**. Similarly, a melody note of E in the context of IV/**C** would be unstable as it is not a chord tone. Unlike Krumhansl's key profile, Lerdahl's Basic Diatonic Space of IV/**C** would show E as less stable then F.

Neither music theory nor empirical data support Lerdahl's added tension value of one when either the fifth or the third of a chord are in the soprano. Lerdahl's own Basic Diatonic Space shows the fifth of the chord as more stable than the third. All agree a melody with the root in the soprano is the most stable arrangement.

Inversion

According to Lerdahl, root position chords are more stable than either first or second inversion chords. For chords in both first and second inversion, Lerdahl adds a tension value of two, as he considers inverted chords less stable than non-root melodic tones (which receive a tension added value of one). His reasoning is related to the fact that chords inhabit level *c* of the Basic Diatonic Space—two levels below that of the root of the chord. He does not consider, in the Basic Diatonic Space, the fifth is shown to be more stable than the third. This suggests, following Lerdahl's reasoning, a chord with the fifth in the bass (one below the root) should have a tension added value of one, while a chord with the third in the bass (two levels below the root) should have a tension added value of two. This may be because such a comment runs contrary to music theory, which designates the first inversion (third of the chord in the bass) as more stable than the second inversion (fifth of the chord in the bass). Furthermore, by this same reasoning, a soprano melody in which the third of a chord is present should add a tension value of two, because that pitch class also appears, at its most stable, two levels below that of the root. This runs contrary to the Scale Degree category above for which he stipulates the third of a chord, when in the melody, should add a tension value of one.

Once again, music theory does not agree with Lerdahl's decision to equate the stability of first and second inversion chord positions. Instead, music theory asserts a chord in second inversion is more unstable than is its first inversion. When discussing the inversion of chords, Rameau states, "although the two chords [first and second inversions] derived from the perfect [root position] are consonant, they are called imperfect, not only to distinguish them from the chord which is their source, but also to indicate that their properties differ from those of their source."[253] This is true for both major and minor chords.

According to Schoenberg, "the root position [of a chord] … presents the strongest form of the triad, then the two dissimilar imitations, the inversions, are the weaker forms."[254] For Schoenberg, this weakness translates into tonal ambiguity. Thus, when discussing the beginning and end of a piece, the first inversion triad, "as the weaker

[252] The key profiles for the major and minor modes differ in their ordering of tone stability. The minor key profile indicates the third is more stable than the fifth.
[253] Rameau, 40.
[254] Schoenberg (1978), 55.

form of the triad, in less suitable than the root position."[255] Schoenberg also suggests the second inversion is less stable than the first inversion. When explaining the harmonic use of these chords he says, "the sixth chord [first inversion] offers scarcely any problems, and the only reason we are drawn into a more detailed discussion of it is that restrictions were imposed on the other inversion, the six-four chord [second inversion]."[256]

Piston describes the character of the first inversion chord as, "lighter, less ponderous, less blocklike, than the same triad in root position."[257] He considers the six-four chord to be "an unstable chord."[258] As with the category of *Scale Degree*, Lerdahl's tension added values for *Inversion* are not consistent with beliefs of music theory.

Little empirical research has considered the effect of chord position on listeners' experience of tension. In a pilot study, Roberts and Shaw found "triads in first inversion were judged as less consonant [by highly trained musicians] than triads in root position." [259] Roberts and Shaw[260] also found highly trained musicians heard first inversion chords of any quality (major or minor) as similar to their corresponding root position chords. Krumhansl found "the dissonance of major, minor, and diminished chords depends strongly on the inversion."[261]

The consensus of music theory and music perception is that the root position is the most stable/least tense position of a chord. The first inversion is less stable/more tense, and the second inversion even more unstable/tense. It appears, for this category of surface tension, the presence or absence of a musical context is less significant. However, contrary to Lerdahl's tension added values, it seems appropriate, when considering the effect of the fifth and the third of a triad as bass notes, to assign different added tension values.

Nonharmonic Tones

Nonharmonic tones are dissonant, unstable tones exhibiting the tendency to resolve to the nearest more consonant, stable tone. Lerdahl's *Surface Tension Rule* does not differentiate between the affects of the various types of nonharmonic tones or the voice in which they appear (top, middle, bottom). For example, a passing tone and an appoggiatura receive equal added tension values. Music theory does not consider the effect of a passing tone to be equal to that of any form of appoggiatura. Lerdahl, however, does differentiate between the effect of diatonic and nondiatonic nonharmonic tones. Diatonic nonchord tones receive an added tension value of 3. Lerdahl's explanation is once again based on his Basic Diatonic Space. Diatonic nonchord tones are found three levels below the root in the Basic Diatonic Space. Nondiatonic nonchord tones receive an added tension value of 4 because they are found four levels below the root in the Basic Diatonic Space. Sevenths[262] add a tension value of 1 (making its effect equal to that of scale degree in the melody) because, if they were considered part of the chord, they would appear at the level of the triad, and would add one to variable *k* (common tone variable). Lerdahl does not differentiate between qualities of sevenths or their supporting triads, such that the effect of a diatonic seventh add to I/**C** (major seventh added to a major triad) is equivalent in added tension to a diatonic seventh added to V/**C** (minor seventh added to a major triad) or vii^{o}/**C** (minor seventh added to a diminished triad).

255 Schoenberg (1978), 55.
256 Schoenberg (1978), 56.
257 Piston, 68.
258 Piston, 169.
259 Roberts and Shaw, 113.
260 Roberts and Shaw, 121.
261 Krumhansl (1990a), 174.
262 I assume Lerdahl means diatonic sevenths.

Schenker, writing on the use of nonchord tones, suggests an unequal effect on the listener of changing notes and suspensions when he writes, "[h]ow is this concept [changing note] to be distinguished from that of the suspension, if both are dissonances on the accented part of the measure … the suspension strives, above all, to produce the effect of a dissonance, while the changing note has more the character of a passing note and conveys a dissonant effect only secondarily." [263]

Gauldin describes the aural effect of unaccented nonharmonic tones as having "an embellishing or 'nonessential' effect—that is, their weak metric placement de-emphasizes the dissonance."[264] Comparing the character of accented (appoggiatura) and unaccented (passing) nonharmonic tones, he says, "[i]n contrast to unaccented non-harmonic tones, appoggiaturas have a more 'essential' character … its resolution 'sweeter.' Their removal from the texture seriously deprives the music of much of its expressive quality."[265]

Piston asserts not all seventh chords have the same effect saying, "nondominant seventh chords, whatever their type, are distinguished from the dominant seventh above all by sound. Beyond that they are distinguished from each other by structural type."[266] He describes the half-diminished seventh as having "less dominant strength than the dominant seventh."[267] The major seventh chords have "a sharper interval than the minor seventh, and these chords thus have a certain pungency … The mixed-mode *e* chords [major-minor seventh] have … a correspondingly greater pungency."[268]

Cadwallader and Gagné believe the effect of all nonharmonic tones is not equal. "Because the suspension occurs on the strong part of the bar; it has the strongest effect of the three [passing, neighbour, and suspension] fundamental dissonances."[269]

Krumhansl's key profile,[270] with its hierarchy of stability, tells us about the relationship of pitch classes to the tonic chord but not about their relationships with other chords. For example, in the context of I/**D**, E is an unstable diatonic nonchord tone creating some tension. However, in the context of ii/**D**, E is a stable diatonic chord tone rising to the level of the root in Lerdahl's Basic Diatonic Space, thus creating little tension. E^b in the context of either I/**D** or ii/**d** is a most unstable chromatic nonchord tone creating the most tension.

Bharucha's concept of melodic anchoring,[271] which Lerdahl incorporates into his calculation of melodic attraction,[272] is relevant to this category of added tension. Bharucha found unstable, nonharmonic tones anchor to or need to resolve to proximate, stable, harmonic tones. Two constraints govern melodic anchoring—asymmetry and

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[263] Schenker (1954), 311.
[264] Gauldin, 61.
[265] Gauldin, 62.
[266] Piston, 348.
[267] Piston, 349.
[268] Piston, 349.
[269] Cadwallader and Gagné, 34.
[270] Krumhansl 1982 and 1990a.
[271] Bharucha 1984a.
[272] Lerdahl incorporates the Basic Diatonic Space (based on Krumhansl's key profile) and Bharucha's melodic anchoring constraints in his *Melodic Attraction Rule*. This rule states the attraction of p_1 to p_2 is equal to the depth of embedding (or stability) of p_2 divided by the depth of embedding (or stability) of p_1 times one divided by the square of the semitone distance between the two tones $[(s_2/s_1) \times (1/n^2)]$.

proximity. The asymmetry constraint states unanchored nonharmonic tones must precede harmonic tones. The proximity constraint states a nonharmonic tone anchors to the closest harmonic tone.

Empirical data indicate listeners perceive added tension in the sounding of nonharmonic tones. These data do not differentiate between the various nonharmonic tones and their effect upon the listener. Music theory also indicates listeners perceive added tension when hearing nonharmonic tones and does create an informal hierarchy of effect where, for example, accented nonharmonic tones add more tension than do unaccented nonharmonic tones.

Lerdahl, when defining the *Surface Tension Rule,* combines the above factors additively such that the surface tension associated with any chord is equal to the tension arising from the chord tone found in the melody (possibly adding 1), plus the tension arising from the inversion of the chord (adding 2), plus the tension arising from nonharmonic tones in the melody (adding 1 for sevenths, 3 for diatonic, and 4 for chromatic). This value is then added to the distance between two chords (variables i, j, and k) giving a local value of tension. The addition of tension inherited by subordinate chords from superordinate chords gives a global total of expected tension experienced by listeners familiar with Western tonal music.

Lerdahl recognises he has made no attempt to distinguish between types of nonharmonic tones. As with all the above numerical values, he considers them "first approximations pending empirical feed back." [273] Music theorists in the more distant past and those of more recent times have written on the stability and effect of Lerdahl's contributors to surface tension. In comparison, little empirical research exists.

There are several ways this topic could be addressed. A revision of the model based on existing literature in both fields (music theory and empirical data from music perception). However, as already stated, presently, there is little empirical data to support such an endeavour. Suggested revisions could be combined with experimental design(s), which could lead to a revision of the assigned tension values for components of surface dissonance. Of more value would be the combination of existing literature with actual experiment(s) leading to support for and/or revision of the assigned tension values for Lerdahl's components of surface dissonance.

Devising an Experiment

At present, there is not enough information in music theory or music perception to allow for a confident assessment leading to a modification of the tension added values in Lerdahl's *Surface Tension Rule*. There is enough information, however, to suggest modification is necessary. Obtaining empirical data would aid in this undertaking. Yet designing effective experiments is not without pitfalls.

Scale Degree

Four-note chords (soprano, alto, tenor, and bass, i.e., SATB) in both open and close positions and differing in the soprano note could be created. The range of pitches would be F_2 (87.31 Hz) to G_5 (783.99 Hz)—the range of pitches usually associated with chords written in SATB form. Following traditions of music theory, the distance between the successive voices would be no more than an octave. The chords would be transposed into all major and minor keys and their presentation randomised. Listeners could be asked to rate on a 100-point scale how tense the

[273] Lerdahl (2001), 150.

chord sounds with 0=no tension and 100=most tension.[274] Unlike the experiments of Krumhansl, Lerdahl's *Surface Tension Rule* is concerned with the psychoacoustic effect of chord structure. Thus, a tonal context is not necessary for obtaining instructive findings regarding listeners' sense of tension when each of the three triad tones are found in the melody. Between the presentations of each chord, a sequence of pitches would be played to disrupt any imposed tonal hierarchy.

Inversion

Once again, because added tension is due to psychoacoustics, a tonal context is not necessary for this category. Chords would be presented singly, devoid of tonal context. Four-note chords, following the guidelines above, would be used here as well. Following rules of harmony, the root would be double in root position chords and the bass note in second inversion chords. The rule for doubling in first inversion chords is not as clear. It is not possible, in first inversion, to double the root or the fifth when the melody note is the third. Perhaps the best solution for doubling in first inversion, then, would be to double whatever note is in the soprano. As above, the chords would be transposed into all major and minor keys and presentation would be randomised. Again, listeners would be asked to rate on a 100-point scale how tense the chord sounds.

Nonharmonic Tones[275]

Creating stimuli for this category is trickier. In the two categories above, metric accent was not of concern, as it is in this category. It would be necessary for the stimuli to create a sense of accented and unaccented beats as some nonharmonic tones occur on accented beats while others occur on unaccented beats. Also, melodic contour and approach to the nonharmonic tone now must be considered when creating stimuli. It is not possible for the melodic contour to remain consistent when considering nonharmonic tones. Suspensions, escape tones, and appoggiaturas generally resolve downwards as do upper neighbour tones. Lower neighbours, however, resolve upwards. Passing tones and changing tones go both ways. Furthermore, the interval of resolution is a third for escape tones but a diatonic or chromatic step for suspensions, appoggiaturas, passing tones, and neighbour tones. The approach to nonharmonic tones can be equally difficult as, for example, appoggiaturas may be approached by step, by leap, or prepared in the preceding voice. Stimuli in the category of nonharmonic tones would necessitate the use of two and sometimes three chords. Complications of tonal hierarchy and the creation of accented and unaccented chords ensue.

Thus, the experiment discussed below evaluates the tension added due to *Inversion* and *Scale Degree* as designing experiments for these categories is much less complicated than designing experiments to evaluate tension added due to *Nonharmonic Tones*. Also, the testing is limited to major and minor chord qualities. There are several reasons for this decision. First, the time required for participants to rate the perceived tension of sufficient trials of four chord qualities, each with three different positions and three different melody notes, is unreasonable. Secondly, Krumhansl eliminated augmented chords from her trials "because the III in the minor only rarely appears as an augmented chord."[276] Furthermore, the position of an augmented chord is not discernable audibly, due to the

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[274] Lerdahl prefers to use the terms 'tension' and 'relaxation' rather than stable/unstable or consonant/dissonant. The terms tension/relaxation incorporates the cognitive dissonance/consonance of stability and sensory dissonance/consonance as well invoking the sense of physical motion. (Lerdahl and Krumhansl 2007, 329-330).
[275] The selection of nonharmonic tones discussed here is by no means exhaustive. Rather, I have chosen a few representative nonharmonic tones which exemplify my points.
[276] Krumhansl (1990), 169.

intervals from which it is composed.[277] Diminished chords are also eliminated from this study because creating a suitable disruptor sequence for these chords was difficult. Lerdahl generally regards diminished triads as rootless seventh chords. In particular, he considers vii^o a rootless V^7 chord thus designating its fifth a nonharmonic (added seventh) tone.

The Experiment

As shown in Figure 3.1, participants hear a sequence of disruptor tones,[278] silence, and then a four-note chord target chord.[279] This target chord will be followed by a time of silence during which participants will record their rating. The same sequence of disruptor tones will follow the presentation of the target chord. After a second of silence, the process is repeated for each of the 216 target chords flanked by their associated sequence of disruptor tones. The range of the disruptor sequences will begin one or two semitones below the lowest tone of the target chord and ascend ending one or two semitones above the highest tone of the target chord. This sequence is based on the major pentatonic scale formed on the tone a tritone away from the root of a major chord and a tritone away from the third of a minor chord. This results in a disruptor sequence with no semitones and no tones in common with its associated target chord.

When two chords are heard in succession, listeners familiar with Western tonal music impose a chordal hierarchy. Disruptor sequences are used in this study to avoid this situation. The purpose of this study is to measure tension added due to surface dissonance alone rather than in combination with tonal tension due to the hierarchical nature of Western tonal music. This leads to another reason augmented chords were eliminate from this study. It was not possible to find a major pentatonic scale that did not share at least one tone with an augmented chord.[280]

Figure 3.1. Disruptor sequences, silences, and target chord.

[277] Let us take the augmented triad D-F$^\#$-A$^\#$ as an example. The distance between D and F$^\#$ is four semitones, as is the distance between F$^\#$ and A$^\#$, as is the distance between A$^\#$ and D. The distances between the tones of the major triad D-F$^\#$-A are all different—D-F$^\#$ is 4 semitones, F$^\#$-A is 3 semitones, and A-D is 5 semitones.
[278] The duration of disruptor tones is dependent upon the range (between the bass and soprano) of their associated chords. Chords with a smaller range will require fewer disruptor tones while chords encompassing a greater range will require more disruptor tones. This is evident in the example provided above.
[279] While some target chords were in close position (2 of 18), the majority of target chords were in open position (16 of 18). See Appendix B for examples of all chord formations and associated disruptor sequences.
[280] A similar problem existed when basing the disruptor sequence on the major pentatonic scale a tritone from the root of a minor triad. This problem was solved by basing the disruptor sequence on the root of its relative major.

Based on tenets of music theory and the available empirical evidence, I hypothesise listeners will rate root position chords as less tense than first inversion chords which will be rated as less tense than second inversion chords. I expect the greatest difference to be found with second inversion chords, with first inversion chords rated only slightly tenser than root position chords. I further hypothesise the chords with the root in the soprano to be rated as least tense and chords with the third in the soprano as more tense. I expect chords with the fifth in the soprano to be rated more closely to those with the root in the soprano. I hypothesise as well the effect of scale degree to be most evident with root position chords. I expect inversion to carry more weight than scale degree when the chord presented is in second inversion.

Method

Participants

Eighty-two musicians (60 women, 22 men) participated in this study.[281] Of the 82, 41 were labelled as Novice musicians and 41 as Expert. For the purposes of this study, Novices are defined as pursuing an undergraduate degree in music, or with less than twenty years performing experience and pursuing music as a hobby. Experts are defined as having completed an undergraduate degree in music, and/or graduate music degree, and/or with more than twenty years performing experience. [282] The mean age of participants was 39.5 (SD = 17.33) years—37.3 (SD = 14.29) years for Novices and 41.7 (SD = 19.86) years for Experts. Mean weekly hours of actively listening to music was 9.8 (SD = 8.57) for Novices and 20.5 (SD = 11.4) for Experts. Mean weekly hours of passively listening to music was 15.41 (SD = 12.81) for Novices and 14.0 (SD = 9.94) for Experts.[283]

Of the participants, 40 indicated piano as their primary instrument. Other primary instruments were cello (1), clarinet (4), flute (1), guitar (4), harp (1), harpsichord (1), organ (1), saxophone (2), trumpet (4), viola (2), violin (1), voice (14). Three Novice musicians played instruments in high school. As it had been many years since they had played these instruments they did not record a primary instrument. Sixty participants (31 Novice and 29 Expert) reported playing a second instrument.

All participants reported normal hearing and none reported having absolute pitch. Participants were studying, or had studied, and were involved in the performance of, Western tonal music. Participants were recruited from among students and teachers at private music studios in Oakville, Hamilton, Waterloo, and Stratford Ontario, and from among students at York, Laurier, and Waterloo Universities. They were not paid for their participation in this study, which required approximately one and one half hours to complete. At the end of the testing phase, participants completed a questionnaire describing their musical training and music listening habits. Explicit knowledge of music theory was not a perquisite for participation in this study. Finally, the testing phase ended with

[281] Sample size was chosen to provide 95% power, based on an a priori power analysis using effect sizes from similar previous studies.

[282] Due to the imprecision of the question on the questionnaire it is not possible to present meaningful comparative data. Novice musicians tended to report how long they had played their instrument. Expert musicians tended to report how long it took to achieve their university degree or their diploma from the Royal Conservatory of Music but did not include years spent performing. See Appendix K for further discussion.

[283] Active listening occurs when participants practice, perform, attend concerts, teach, or whenever the participants' focus is music. Passive listening occurs when other activities are the primary focus and are performed in the presence of music. Reading or working while music plays in the background are examples of passive listening.

an informal discussion during which each participant was asked to report on the test itself, their experience of the test, and for any other comments.

Materials

Chords and disruptor sequences were played back using E-Studio 2.0 on Lenovo ThinkPad's Realtek High Definition Audio through Sennheiser HD 280 pro headphones. In order to allow the chords to sound for 4s, all the chords were created in Apple's *GarageBand* with the Steinway grand piano sound coupled with a synth pad sound. Disruptor sequences used only the Steinway grand piano sound. Participants heard a disruptor sequence,[284] a 2s silence, and a four-note target chord for 4s (in both open and close positions). This target chord was followed by another 2s silence during which participants recorded their rating. The same disruptor sequence followed. After a 1s silence, the process was repeated for each of the 216 target chords, each flanked by their associated disruptor sequence. The disruptor sequences began 1 or 2 semitones below the lowest tone of the target chord, and ascended ending 1 or 2 semitones above the highest tone of the target chord. This sequence was based on the major pentatonic scale formed on the tone a tritone away from the root of a major chord, and a tritone away from the third of a minor chord. This results in a disruptor sequence that has no tones in common with its associated target chord. The expectation was the disruptor sequences would disallow a tonal hierarchy to be created as is likely to happen when major and minor chords are heard in succession.

The four-note chords (soprano, alto, tenor, and bass) were created in both open and close positions[285] with differing soprano notes (identified as 'Melody') and differing bass notes (identified as 'Inversion').[286] The notes of the soprano and bass each could be one of three possibilities—the root of the chord (labelled as 1 for Melody and R for Inversion), the third of the chord (labelled as 3 for Melody and F for Inversion), or the fifth of the chord (labelled as 5 for Melody and S for Inversion). The range of pitches was from F_2 (87.31 Hz or the space below bottom line of the bass staff) to G_5 (783.99 Hz or the space above the top line on the treble staff). Following traditions of music theory, the distance between the successive voices was no more than an octave. The chords were transposed into all major and minor keys resulting in 216 chords. The chords were divided into 6 blocks of 36 chords, and presented with 3 minute rest periods between blocks. The chords within the blocks were presented in random order. The presentation order of the blocks was also randomised in the manner of Latin squares.[287]

[284] The duration of disruptor tones is dependent upon the range (between the bass and soprano) of their associated chords. Chords with a smaller range will require fewer disruptor tones while chords encompassing a greater range will require more disruptor tones. This is evident in the example provided above.

[285] The distance between the lowest and highest notes of a chord in close position is an octave or less. The distance between the lowest and highest notes of a chord in open position is greater than one octave.

[286] The upper case letters for the words Inversion, Melody, chord Quality, and Expertise identify them as the four factors in the study. Similarly, upper case letters for Root, First, Second, and Major identify them as levels of factors in this study. While minor is also a level in this study, it begins with a lower case letter following the tradition of identifying minor chords and regions with lower case letters.

[287] Latin squares allow for some tests to run as blocks 1, 2, 3, 4, 5, and 6, while others were blocks 2, 3, 4, 5, 6, and 1, and still others were blocks 3, 4, 5, 6, 1, and 2, and so forth. See Appendix C for a more detailed description of the randomisation process.

Procedure

Participants were instructed to rate on the sliding scale presented on the screen of the laptop, the amount of tension they perceive was embodied in the major and minor chords they heard.[288] The purpose of the disruptor sequences was explained so participants did not attempt to relate the target chord to its disruptor sequence. They were further instructed to decide on their rating while listening to the chord, as the 2s allotted for recording their rating did not allow for time to think. It was explained to the participants the accuracy of their perception of tension was not being tested. Rather, it was the ability of Lerdahl's model to predict their experience that was being tested. The testing phase was preceded by a training phase consisting of 7 chord formations chosen randomly from the pool of 216 chord formations heard during the testing phase. No participant heard the same 7 chord formations in the training phase. The training phase familiarised the participants with the sound of the stimuli, allowed them to adjust to the mouse and slider interaction, and prepared them for the short time allotted for recording their perceived tension rating.

Results[289]

The results of the descriptive statistics and histograms showed skewed distributions for all 18 chord formations. Appendix E explains the reasoning behind using the median rather than the typically used mean to represent the central tendency of participants' ratings. Boxplots of participant means of medians for each of the 18 chord formations revealed 21 outliers[290] spread over 9 chord formations. The outliers were removed, descriptive statistics were obtained, and ANOVA was performed on these data. This information is found in Appendix F, as is the rationale for reporting statistics for the data with outliers rather than the data without outliers.

Table 3.1 gives the means of the medians of the perceived tension and the standard deviation for each chord formation. A graph illustrating the means of the medians and 95% Confidence Interval, for all chord formations, is shown in Figure 3.2. The two levels of Expertise (Novice and Expert) are combined. The reason for this (ANOVA determined there was no effect of Expertise) is discussed below.

[288] In order to encourage participants to use the entire range of the scale, they were told only major and minor chords would be presented. This meant they were not expecting to hear augmented, diminished, or seventh chords, which are usually considered tenser than either major or minor chords.
[289] See Appendix D for an explanation of the statistical terminology and statistical procedures.
[290] R1M (1-high), R3M (2-high), S3M (1-high), S5M (1-high), R5n (1-low), F1n (8-low), F5n (1-low), S1n (2-low), S3n (3-low), and S5n (1-low)

Table 3.1.

Means of medians, Standard Deviation, and Margin of Error for all chord formations

Chord	Mean	SD	MOE	Chord	Mean	SD	MOE
R1M	24.20	20.43	4.49	R1n	56.53	21.18	4.65
R3M	20.15	17.35	3.81	R3n	48.49	19.74	4.34
R5M	22.61	16.86	3.7	R5n	49.98	18.92	4.16
F1M	36.03	20.65	4.54	F1n	57.19	20.38	4.48
F3M	28.71	17.61	3.87	F3n	53.28	18.89	4.15
F5M	25.30	16.92	3.72	F5n	52.79	19.23	4.23
S1M	34.76	21.67	4.76	S1n	60.90	20.03	4.4
S3M	28.25	18.56	40.8	S3n	59.01	20.15	4.43
S5M	23.62	15.83	3.48	S5n	57.02	21.91	4.81

Note. Chord formations are recorded by Inversion_Melody_chord Quality where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor; SD = Standard Deviation; MOE = Margin of Error for 95% Confidence Interval.

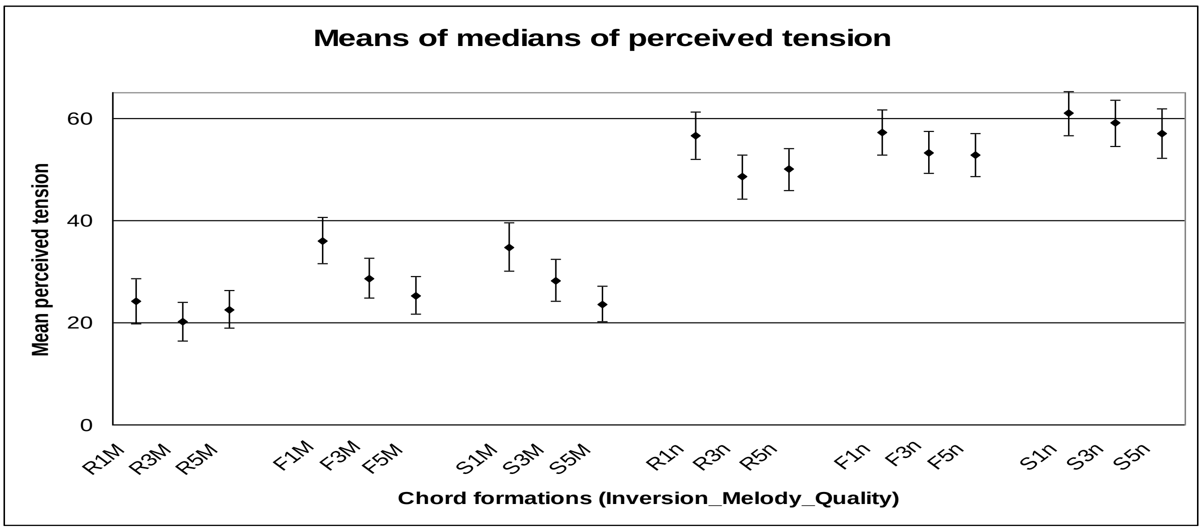

Figure 3.2. Means of medians of perceived tension (Expertise combined) and 95% Confidence Intervals, by chord formation. (Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor).

An analysis of variance (ANOVA), with 3 within subjects factors (Inversion, Melody, and chord Quality), and 1 between subjects factor (Expertise), performed on these data reveal main effects, two-way, three-way, and four-way interactions. The factors Inversion and Melody have 3 levels. They are, for Inversion: Root, First, and Second, and for Melody: 1, 3, and 5. The third within subjects factor, chord Quality, has 2 levels (Major and minor). The between subjects factor, Expertise, has 2 levels (Novice and Expert). Mauchly's Test of Sphericity returned $p < .05$ for the main effect of Melody, and the Inversion*Melody interaction. Therefore, the Greenhouse-Geisser correction is used in these 2 cases. Eta squared (η^2) is one measure of effect size that can be applied to ANOVA results. It assigns a value allowing for a comparison among main effects and interactions.[291] When multiplied by 100, the calculated value provides the proportion of change in the dependent variable (perception of tension) explainable by an independent variable (main effects and interactions of Inversion, Melody, Quality, and Expertise). The results are found in Table 3.2.

[291] Within subjects Eta squared = Treatment Sum of Squares/Total Sum of Squares, where Treatment is main effect and/or interactions and Total is (sum of squares of all main effects) + (sum of squares of all interactions) + (sum of squares of all errors) + (sum of squares of Between subjects error).

Table 3.2.

Analysis of Variance for Perceived Tension in Chord Formations

Source	*df*	*F*	η^2
Between Subjects			
Expertise	1	3.4	.012
Error (Expertise)	80		
Within Subjects			
Inversion	2	45.16•••	.015
Error (Inversion)	160		
Melody	1.81	22.48•••	.013
Error (Melody)	144.79		
Quality	1	214.65•••	.334
Error (Quality)	80		
Inversion*Melody	3.56	3.02•	.002
Error (Inversion*Melody)	284.48		
Inversion*Quality	2	9.14•••	.003
Error (Inversion*Quality)	160		
Melody*Quality	2	2.25	.0006
Error (Melody*Quality)	160		
Inversion*Expertise	2	.65	.0002
Error (Inversion*Expertise)	80		
Melody*Expertise	2	3.62•	.002
Error (Melody*Expertise)	80		
Quality*Expertise	1	.3	.0005
Error (Quality*Expertise)	80		
Inversion*Melody*Quality	4	4.42••	.002
Error (Inversion*Melody*Quality)	320		
Inversion*Melody*Expertise	4	1.0	.0005
Error (Inversion*Melody*Expertise)	80		
Inversion*Quality*Expertise	2	4.32•	.001
Error (Inversion*Quality*Expertise)	80		
Melody*Quality*Expertise	2	.81	.0002
Error (Melody*Quality*Expertise)	80		
Inversion*Melody*Quality*Expertise	4	1.39	.0007
Error (Inversion*Melody*Quality*Expertise)	80		

Note. •$p < .05$, ••$p < .002$, •••$p < .001$.

Paired sample *t*-tests[292] were performed in order to determine where the differences occur for the main effects identified by ANOVA. Table 3.3 summarises the results. Cohen's *d*, is determined by dividing the difference between the means of medians by the pooled standard deviation for those means, and gives the effect size for each paired sample.[293]

Table 3.3.

Paired sample t-tests (two-tailed) for differences between levels of Between subjects factors

Pair	DM	SD	*t*	df	Cohen's *d*	% Above mean[294]	% Overlap	*P* Superiority
Major vs. minor	-27.95	17.2	-14.71**	81	-1.63	94.52	42.37	87.11
Root vs. First	-5.22	7.15	-6.62**	81	-.73	75.8	72.63	68.97
Root vs. Second	-6.94	7.28	-8.63**	81	-.95	81.59	65.27	73.77
First vs. Second	-1.71	6.12	-2.53*	81	-.28	61.79	88.08	58.4
Melody 1 vs. Melody 3	5.29	10.46	4.58**	81	.52	69.15	80.26	63.82
Melody 1 vs. Melody 5	6.38	9.7	5.96**	81	. 7	75.8	72.63	68.97
Melody 3 vs. Melody 5	1.09	7.72	1.28	81	. 14	53.98	96.01	52.82
Root 3 vs. Root 5	-1.97	9.45	-1.89	81	-.21	57.93	92.03	55.62
First 3 vs. First 5	1.95	11.39	1.55	81	.17	57.93	92.03	55.62
Second 3 vs. Second 5	3.31	13.1	2.29*	81	.25	57.93	92.03	55.62

Note. DM = difference of means of medians, SD = standard deviation of difference, 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; % above mean indicates the percent of ratings for one level of a factor will be above the mean of medians of another level, % overlap indicates the percent of overlap between the distributions of the two levels, *P* superiority indicates the chance the rating of a random participant will agree with the findings of two-tailed *t*-test; $*p < .05$, $**p < .001$.[295]

Discussion

In general, the means of the medians of perceived tension (Figure 3.2) are higher for minor Quality chords than for Major Quality chords. The means of the medians for each formation of Major Quality chords is lower than

[292] Negative values for *t*-statistic mean the subtracted mean of the median was larger then the first mean of median. This is obvious from the values in the DM (difference of means) column. For example, the mean of median for perceived tension in minor chords is larger then the mean of median for perceived tension in Major chords. Thus, when minor is subtracted from Major, the DM, *t*-statistic, and Cohen's *d*, will all be a negative value.

[293] d = (mean of median of variable1 - mean of median of variable 2)/[√(standard deviation of variable1^2 - standard deviation of variable 2^2)/2]. See footnotes 288 and 293 for explanations of negative values.

[294] The values for % above mean, % overlap, and probability of superiority were calculated using the website www.rpsychologist.com/d3/cohend/ created by Kristoffer Magnusson. Magnusson's representation allows for only one decimal place for Cohen's *d*. Thus, Cohen's *d* of 1.63 would be entered as 1.6 and Cohen's *d* of .17, .21, and .25 as .2. While this means the values obtained using Magnusson's algorithm are close to but not exact interpretations of Cohen's *d*, these approximations are more useful than the small, medium, and large usual interpretations of Cohen's *d*.

[295] Bonferroni correction for chord Quality sets $\alpha = .025$ (.05/2). The difference between the means of Major and minor is still significant at this level of α. Bonferroni correction for Inversion and Melody sets $\alpha = .017$ (.05/3). All *t*-tests for Inversion are significant at this level also. Results of *t*-tests for Melody do not change. A Bonferroni correction is not necessary for the Inversion*Melody interactions as only a portion of the data set was used.

the means of the medians of the same minor Quality chord formation. The Margins of Error around the means of the medians of perceived tension are of the same general magnitude for minor Quality chord formations and Major Quality chord formations. The 95% Confidence Interval for chord formations of both chord Qualities indicates a high confidence the population mean will be found between the lower and upper limits of the Confidence Interval. The small range of values indicates a high level of consnsus in identifying the mean of perceived tension for a population familiar with Western tonal music.[296]

Inversion

This study found the means of the medians of perceived tension by all participants (Table 3.1 and Figure 3.2) confirm beliefs held by music theory, and Lerdahl's model of surface tension, as Root position chords are perceived as less tense than are First Inversion chords, and First Inversion chords as less tense than Second Inversion chords. This is true for both Major and minor chord Qualities. Analysis of variance found a main effect of Inversion upon participants' perception of tension in chords presented outside of a musical and tonal context, $F(2, 160) = 45.16$, $p < .001$. As evidenced by eta squared (Table 3.2), Inversion alone accounts for a small proportion (1.5%) of change in perception of tension.

The paired samples *t*-test (Table 3.3) indicates the tension perceived when hearing Root position chords is different from tension perceived when hearing First Inversion chords and Second Inversion chords. The difference is greater between Root and Second Inversion (Cohen's $d = -.95$, indicating approximately 65.27% overlap of the distributions, approximately 81.59% of ratings for Second Inversion are higher than those for Root position, and approximately 73.77% probability a randomly chosen participant would rate Second Inversion as tenser than Root position)[297] than between Root and First Inversion (Cohen's $d = -.73$, indicating approximately 72.63% overlap of the distributions, approximately 75.8% of ratings for First Inversion are higher than those for Root position, and approximately 68.97% probability a randomly chosen participant would rate First Inversion as tenser than Root position). This aligns with the tenets of music theory and Lerdahl's *Surface Tension Rule* as both assert Root position chords are more stable (less tense) than either First or Second Inversions. Music theory also states First Inversion chords are perceived as less tense than are Second Inversion chords. This is supported by the results in Table 3.3 as the paired samples *t*-test, $t(81) = -2.53$, $p < .05$, shows Second Inversion chords, to a small degree, are heard as more tense than are First Inversion chords (Cohen's $d = -.28$, indicating approximately 88.08% overlap of the distributions, approximately 61.79% of ratings for First Inversion are lower than those for Second Inversion, and approximately 58.4% probability a randomly chosen participant would rate First Inversion as less tense than Second Inversion). Lerdahl does not differentiate between First and Second Inversion chords and adds a tension value of 2 for both.

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[296] The population mean is estimated by the mean of medians in this study. The 95% Confidence Interval at *Figure 3.2* indicates the probability of finding the population mean outside of this small range is .05 and finding the population mean within the same small range is .95. Effect Sizes and 95% Confidence Intervals are discussed in more detail in Chapter 4.

[297] To determine the numerator of Cohen's *d*, the means of the two variables being tested are subtracted. The value for Cohen's *d* is negative because the mean of First Inversion, which is larger than the mean of Root, was subtracted from the mean of Root. The value for Cohen's *d* would be positive if the mean of Root was subtracted from the mean of First Inversion. The sign indicates which mean, first or second, was larger. The numerical value indicates the effect size.

These results suggest tension added due to chords in First Inversion should have a smaller value than tension added due to chords in Second Inversion.

Melody

This study found a main effect of Melody upon listeners' perception of tension in chords presented outside of a musical and tonal context, $F(1.81, 144.79) = 22.48$, $p < .001$. As evidenced by eta squared (Table 3.2), Melody alone accounts for a small proportion (1.33%) of change in perception of tension. Table 3.1 and the graph in Figure 3.2 show, regardless of Inversion and chord Quality, the means of the medians of chord formations with the root (1) in the Melody are perceived as more tense than are those with either 3 or 5 in the Melody. This is contrary to the tenets of music theory, and Lerdahl's model of surface tension. Both music theory and Lerdahl's model predict chords with the root (1) in the Melody are less tense than are chords with either 3 or 5 in the Melody. Music theory predicts Melody 3 should be the most tense, then Melody 5 with less tension, and Melody 1 with the least tension. Lerdahl's added tension values of 1 for chords with either 3 or 5 in the Melody and 0 for Melody 1 are not reflective of the results obtained by this study.

Support for these observations is found in the results of the paired samples *t*-tests (Table 3.3) which indicate the perceived tension of Melody 1 is different from the perceived tension of Melody 3 and Melody 5. Cohen's *d* indicates the difference in perceived tension between Melody 1 and Melody 5 (Cohen's $d = .7$, indicating approximately 72.63% overlap of the distributions, approximately 75.8% of ratings for Melody 1 are higher than those for Melody 5, and approximately 68.97% probability a randomly chosen participant would rate Melody1 as tenser than Melody 5) is larger than that between Melody 1 and Melody 3 (Cohen's $d =.52$, indicating approximately 80.26% overlap of the distributions, approximately 69.15% of ratings for Melody 1 are higher than those for Melody 3, and approximately 63.82% probability a randomly chosen participant would rate Melody1 as tenser than Melody 3). The positive value for Cohen's *d* indicates, contrary to music theory and Lerdahl's model of surface tension, Melody 1 is perceived as tenser than Melody 3 or Melody 5. Possible reasons for this puzzling result are discussed in chapter 5**.** A *p*-value greater than .05 for the *t*-test between Melody 3 and Melody 5 suggests participants did not perceive the tension in chords with the third in the Melody as different from the chords with the fifth in the Melody. This conclusion is supported by Cohen's *d* (.14, indicating approximately 96.01% overlap of the distributions, approximately 53.98% of tension ratings for Melody 3 are different from those for Melody 5, and approximately 52.82% probability a randomly chosen participant would rate tension due to Melody3 as different than Melody 5), suggesting participants did not perceive a large difference in tension between Melody 3 and Melody 5 chords. This finding aligns with Lerdahl's model of surface tension.

Chord Quality

Descriptive statistics (Table 3.1 and Figure 3.2) demonstrate, regardless of Inversion and Melody, minor Quality chords are perceived as conveying more musical tension than are Major Quality chords. The results of ANOVA (Table 3.2) support this observation as a difference between the ratings of perceived tension for Major and minor chord formations was found, $F(1, 80) = 214.65$, $p < .001$. Unlike Inversion and Melody, eta squared (Table 3.2) reveals chord Quality accounts for a much larger proportion (33.41%) of participants' perception of tension. A paired samples *t*-test (Table 3.3) found the perceived tension for all Major chord formations was different from that of all minor chord formations, $t(81) = -14.71$, $p < .001$. Cohen's *d* (-1.63, indicating approximately 42.37% overlap of the distributions, approximately 94.52% of ratings for minor chord Quality are higher than those for Major chord Quality, and approximately 87.11% probability a randomly chosen participant would rate minor chord Quality as tenser than Major chord Quality) suggests the effect size is large in comparison to the influence of the levels Inversion and Melody, and their interactions. Music theory predicts Major Quality chords are less tense than are minor Quality chords. Lerdahl's model of surface tension does not provide a tension added value for chord Quality.

Expertise

Figure 3.3 shows participants identified as Novice rated all chord formations as more tense than did Expert participants for the same chord formations. During the instruction phase of the study, participants were told they would hear only Major and minor Quality chords, and were asked to rate perceived tension within that context. Even so, Expert participants, reporting a knowledge and experience of chords conveying more tension (e.g. seventh chords and diminished chords), found it difficult not to use their experience of these chords when assigning tension values to Major and minor chords. Thus, in general, Experts were not comfortable giving high tension values to Major and minor chords. Novice participants reported no such difficulty.

During debriefing, Experts reported being aware of Inversion and Melody but found the 4s allowed for rating did not give time to apply this knowledge. For example, Expert participants may have identified a chord as second Inversion, known music theory predicts this chord to be unstable, and thus rated it with higher tension. Experts reported the 4s allotted for participants to decide on the rating and to use the mouse to move the slider to the chosen rating did not allow for the awareness to affect their rating. The results found below in which Melody 1 is rated tenser than either Melody 3 or Melody 5 bear this out. If Experts were able to apply principles of music theory, Melody 1 would be rated as least tense.

Also evident in Figure 3.3 is the similar trend in perceived tension between Novice and Expert participants across chord formations. This observation is borne out as ANOVA (Table 3.2) found no effect of Expertise, F (1, 80) = 3.4, $p > .05$. As well, ANOVA determined there was no interaction of Expertise with Inversion, F (2, 80) = .65, $p > .05$, (demonstrated by the parallel lines in Figure 3.4), and with Chord Quality, F (2, 80) = .3, $p > .05$ (demonstrated by the parallel lines in Figure 3.5). Supporting these results were the inconsequential effect sizes, .0002 and .0005 respectively.

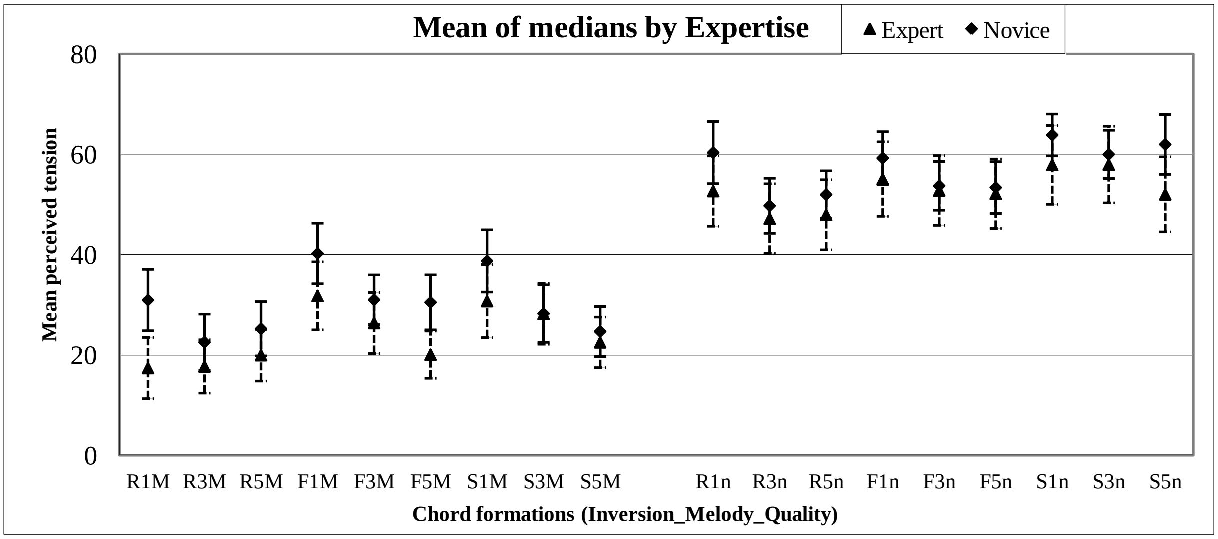

Figure 3.3. Means of medians of perceived tension by Expertise, by chord formation. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor.

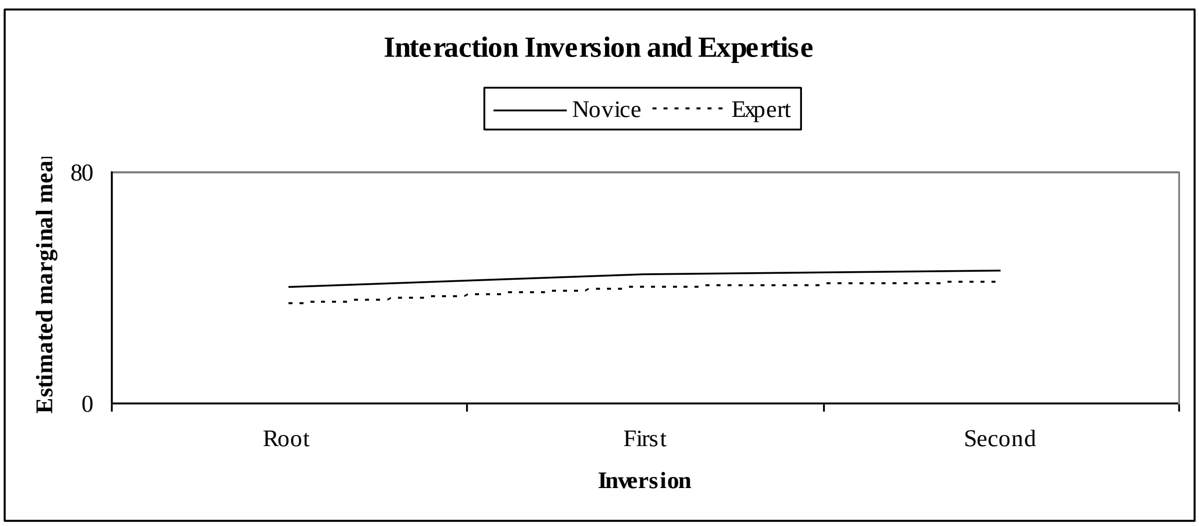

Figure 3.4. Parallel lines indicating lack of interaction between Inversion and Expertise.

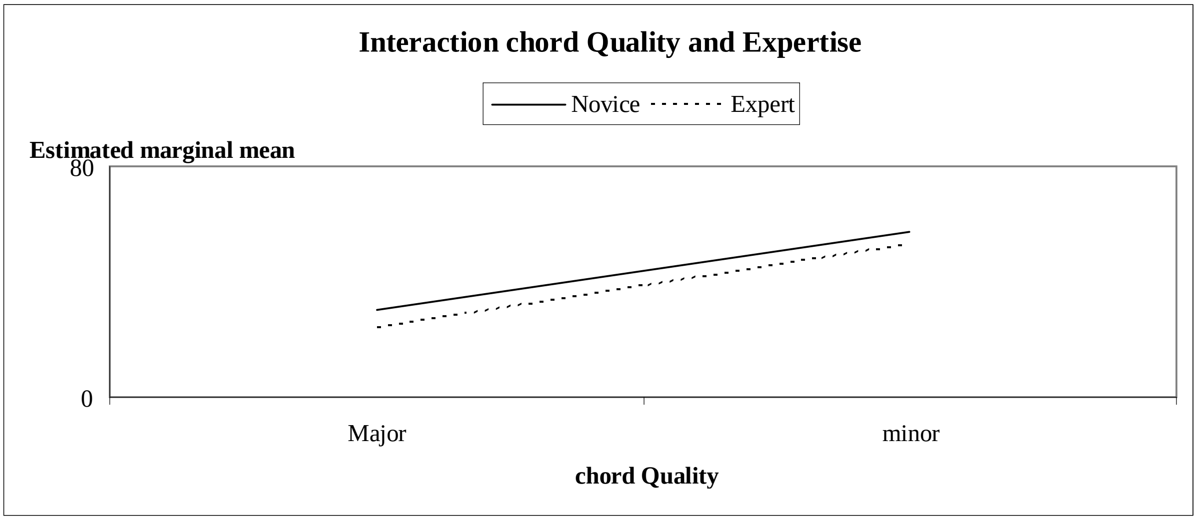

Figure 3.5. Parallel lines indicating lack of interaction between chord Quality and Expertise.

Two-way Interactions

Melody and Expertise

Expertise, however, was found to have a very small effect (η^2=.0021) upon participants' perception of tension as the top chord note (Melody) varied. The interaction, $F(2, 80) = 3.62$, $p < .05$, is observable in the non-parallel lines in Figure 3.6.

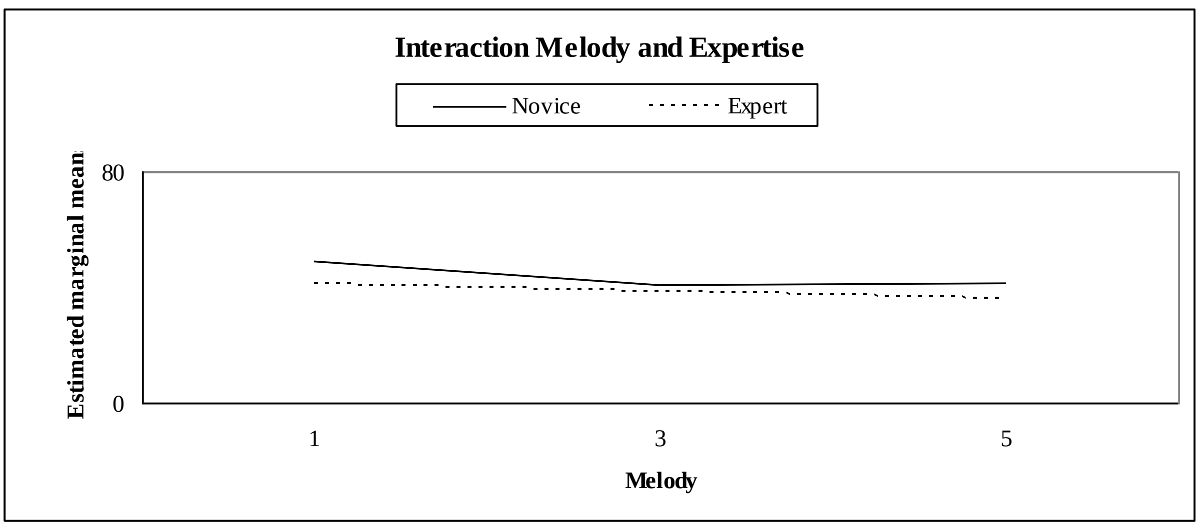

Figure 3.6. Interaction of Melody (1, 3, and 5) with Expertise.

A paired samples *t*-test (Table 3.4) found an effect of Expertise for Melody 1 [t (245) = -4.439, $p < .001$], and for Melody 5 [t (245) = -3.483, $p < .001$], but not for Melody 3 [t (245) = -1.518, $p > .05$]. Expertise appears to have the least effect on the perception of tension in Melody 3 chords (Cohen's d = -.097, indicating approximately 96.01% overlap of the distributions, approximately 53.98% of ratings Novices are higher than those for Experts, and approximately 52.82% probability a randomly chosen Novice participant would rate Melody 3 as tenser than would an Expert participant), and near equal effect for Melody 1 (Cohen's d = -.286, indicating approximately 88.08% overlap of the distributions, approximately 61.79% of ratings Novices are higher than those for Experts, and approximately 58.4% probability a randomly chosen Novice participant would rate Melody 1 as tenser than would an Expert participant) and Melody 5 chords (Cohen's *d* = -.223, indicating approximately 92.03% overlap of the distributions, approximately 57.93% of ratings Novices are higher than those for Experts, and approximately 55.62% probability a randomly chosen Novice participant would rate Melody 5 as tenser than would an Expert participant). The negative value for Cohen's *d* also indicates the mean of medians ratings for Novice participants for each level of Melody was higher than were the mean of medians ratings for Expert participants.

Table 3.4.

*Paired samples t-test (two-tailed) for Melody*Expertise Interaction*[298]

Pair	DM	SD	*t*	df	Cohen's *d*	% Above mean[299]	% Overlap	*P* Superiority
M1_E vs. M1_N	-7.976	28.18	-4.439*	245	-.286	61.79	88.08	58.4
M3_E vs. M3_N	-2.506	25.9	-1.518	245	-.097	53.98	96.01	52.82
M5_E vs. M5_N	-5.516	24.842	-3.483*	245	-.223	57.93	92.03	55.62

Note. DM = difference of means, SD = standard deviation of difference, Melody: M1 = Root of chord in top voice, M3 = third of chord in top voice, M5 = fifth of chord in top voice; E = Expert, N = Novice; % above mean indicates the percent of ratings for one level of a factor will be above the mean of medians of another level, % overlap indicates the percent of overlap between the distributions of the two levels, *P* superiority indicates the chance the rating of a random participant will agree with the findings of two-tailed *t*-test; **p* < .001.

Inversion and chord Quality

The results of ANOVA (Table 3.2) indicate there is an interaction between Inversion and chord Quality, $F(2, 160) = 9.14$, $p < .001$. Eta squared (0.003) suggests this interaction has a small effect on participants' perception of tension in this study. The nonparallel lines in Figure 3.7 illustrate the interaction. It appears the cause may be the result of the interaction between First Inversion chords and chord Quality. This interpretation is supported by the now parallel lines in Figure 3.8. Removal of Major First Inversion and minor First Inversion appears to eliminate the interaction of Inversion and Quality.

[298] Because all the data was subjected to three paired samples *t*-tests all at once, a Bonferroni correction could be applied. In this case, *p*-values < .017 (α = .05/3) would be considered significant.[298]

[299] The values for % above mean, % overlap, and probability of superiority were calculated using the website www.rpsychologist.com/d3/cohend/ created by Kristoffer Magnusson. Magnusson's algorithm allows for only one decimal place for Cohen's *d*. While this means the values obtained using Magnusson's representation are close to but not exact interpretations of Cohen's *d*, the approximations are more useful than the small, medium, and large usual interpretations of Cohen's *d*.

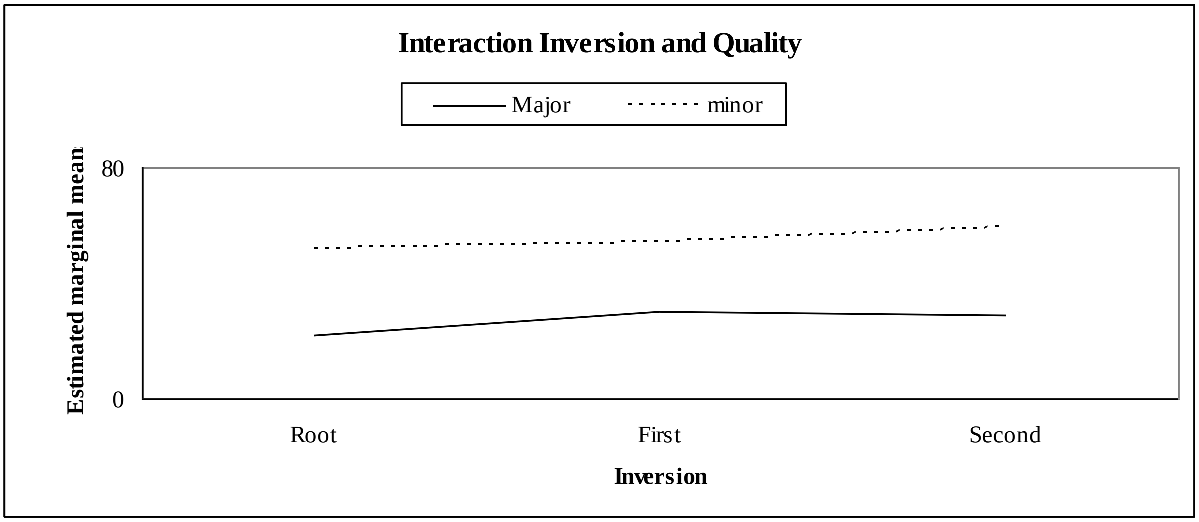

Figure 3.7. Interaction between Inversion (Root, First, and Second) and chord Quality (Major and minor).

A paired samples *t*-test, summarised in Table 3.5, suggests an interaction of Inversion and chord Quality. The magnitude of the differences of means of medians for Root and First Inversion is substantially different for Major and minor Quality chords. This is true also for the difference of means of medians between First and Second Inversion. The difference between Root and Second Inversion means of medians is less dramatic.

The size of the effect also varies with chord Quality. The difference in perceived tension between First and Second Inversion Major Quality chords (Cohen's $d = .124$, indicating approximately 96.01% overlap of the distributions, approximately 53.98% of ratings Second Inversion Major higher than First Inversion Major, and approximately 52.82% probability a randomly chosen participant would rate Second Inversion Major tenser than First Inversion Major) demonstrates a weaker effect than does the difference in perceived tension between the same Inversions, but with minor chord Quality (Cohen's $d = -.578$, indicating approximately 76.42% overlap of the distributions, approximately 72.57% of ratings Second Inversion minor higher than First Inversion minor, and approximately 66.43% probability a randomly chosen participant would rate Second Inversion minor tenser than First Inversion minor). These results support the interpretation of Figures 3.7 (non-parallel lines) and 3.8 (parallel lines)—it was participants' perception of tension embodied in First Inversion chords, and that relationship to Root and Second Inversion chords varying with chord Quality, that was driving the interaction. Chord Quality appears to affect the relationship between Root and Second Inversion chords to a lesser degree.

Table 3.5.

*Paired samples t-test (two-tailed) for Inversion*Quality Interaction*

Pair	DM	SD	*t*	df	Cohen's *d*	% Above mean[300]	% Overlap	*P* Superiority
RM vs. FM	-7.69	10.34	-6.738*	81	-.743	75.8	72.63	68.97
RM vs. SM	-6.56	9.99	-5.943*	81	-.663	75.8	72.63	68.97
FM vs. SM	-5.52	24.842	1.108	81	.124	53.98	96.01	52.82
Rn vs. Fn	-2.75	9.94	-2.75**	81	-.278	61.79	88.08	58.4
Rn vs. Sn	-7.31	9.82	-6.74*	81	-.744	75.8	72.63	68.97
Fn vs. Sn	-4.56	7.96	-5.17*	81	-.578	72.57	76.42	66.43

Note. DM = difference of means, SD = standard deviation of difference, Inversion: R = Root, F = First, S = Second; Quality: M = Major, n = minor; % above mean indicates the percent of ratings for one level of a factor will be above the mean of medians of another level, % overlap indicates the percent of overlap between the distributions of the two levels, *P* superiority indicates the chance the rating of a random participant will agree with the findings of two-tailed *t*-test; **$p < .05$, *$p < .001$.

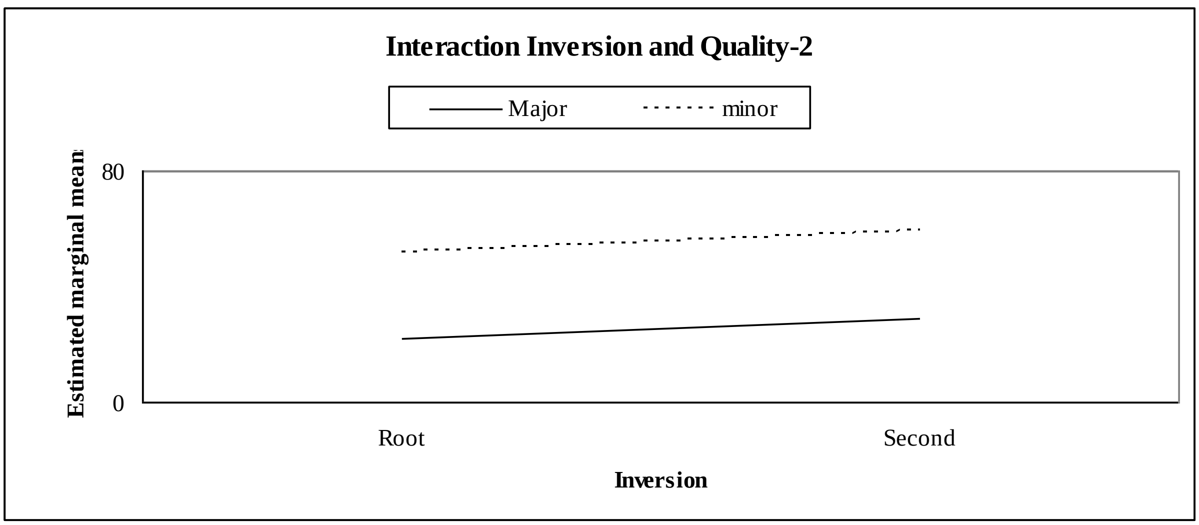

Figure 3.8. Interaction between Inversion (Root and Second only) and chord Quality (Major and minor).

Inversion and Melody

Eta squared (Table 3.2) indicates a small effect (0.0016) for the interaction between Inversion and Melody, $F(3.56, 284.48) = 3.02$, $p < .05$. The nonparallel lines in Figure 3.9 support this finding.

[300] The values for % above mean, % overlap, and probability of superiority were calculated using the website www.rpsychologist.com/d3/cohend/ created by Kristoffer Magnusson. Magnusson's representation allows for only one decimal place for Cohen's *d*. Thus, Cohen's *d* of .74 and .66 will both be entered as .7. While this means the values obtained using Magnusson's algorithm are close to but not exact interpretations of Cohen's *d*, the approximations are more useful than the small, medium, and large usual interpretations of Cohen's *d*.

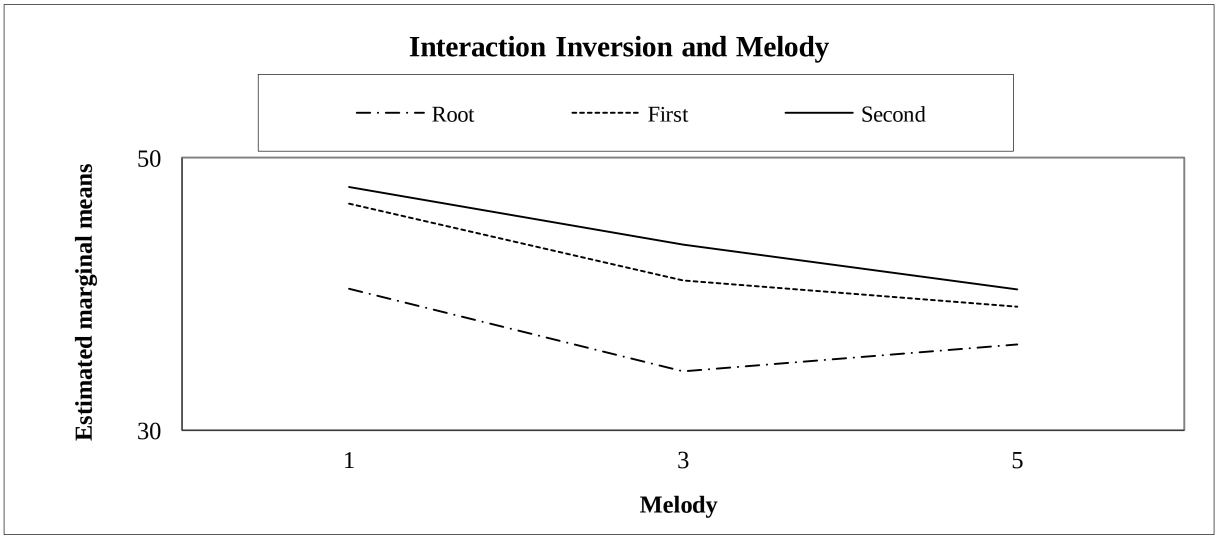

Figure 3.9. Interaction between Melody (1, 3, 5) and Inversion (Root, First, Second).

The results of a paired samples *t*-test (Table 3.6) lend support to Lerdahl's model of surface tension. Regardless of Inversion, chords with Melody 1 and chords with Melody 3 differ in their embodiment of tension. Depending on level of significance, this may be less so for Second Inversion chords. Regardless of Inversion, chords with Melody 1 and chords with Melody 5 also differ in their embodiment of tension. Both Lerdahl and music theory state a chord with the root (1) in the Melody will be perceived as less tense than a chord with either the third (3) or the fifth (5) in the Melody. Music theory states a chord with the third (3) in the Melody is the tenser than a chord with Melody 5. Lerdahl's *Surface Tension Rule* equates the tension added due to Melody 3 with that of Melody 5. The results of the paired samples *t*-test support Lerdahl's model as, regardless of Inversion, tension perceived for Melody 3 and Melody 5 are not different. Once again, depending on level of significance, this may be less so for Second Inversion chords.

For chords in First Inversion, the largest effect size is due to the difference in perceived tension between Melody 1 and Melody 5; (Cohen's $d = .62$, indicating approximately 96.01% overlap of the distributions, approximately 53.98% of ratings First Inversion_Melody 1 higher than First Inversion_Melody 5, and approximately 66.43% probability a randomly chosen participant would rate First Inversion_Melody 1 tenser than First Inversion_Melody 5). The same is true for chords in Second Inversion (Cohen's $d = .525$, indicating approximately 80.26% overlap of the distributions, approximately 69.15% of ratings Second Inversion_Melody 1 higher than Second Inversion_Melody 5, and approximately 63.82% probability a randomly chosen participant would rate Second Inversion_Melody 1 tenser than Second Inversion_Melody 5). For chords in Root position, the largest effect size is between Melody 1 and Melody 3 (Cohen's $d = .46$, indicating approximately 80.26% overlap of the distributions, approximately 69.15% of ratings Root_Melody 1 higher than Root_Melody 3, and approximately 63.82% probability a randomly chosen participant would rate Root_Melody 1 tenser than Root_Melody 3). The values for Cohen's *d* support Lerdahl's *Surface Tension Rule* as the difference in perceived tension between Melody 3 and Melody 5 chords is less than the difference between Melody 1 and Melody 3 chords.

Table 3.6.

Paired samples t-test (two-tailed) Inversion and Melody interaction[301]

Pair	DM	SD	*t*	df	Cohen's *d*	% Above mean[302]	% Overlap	*P* Superiority
R1 vs. R3	6.04	13.54	4.040*	81	0.460	69.15	80.26	63.82
R1 vs. R5	4.07	11.53	3.196*	81	0.365	65.54	84.15	61.14
R3 vs. R5	-1.97	9.45	-1.890	81	-0.209	57.93	92.03	55.62
F1 vs. F3	5.62	12.05	4.219*	81	0.382	65.54	84.15	61.14
F1 vs. F5	7.57	12.84	5.336*	81	0.620	72.57	76.42	66.43
F3 vs. F5	1.95	11.39	1.552	81	0.173	57.93	92.03	55.62
S1 vs. S3	4.20	15.42	2.469**	81	0.275	61.79	88.08	57.4
S1 vs. S5	7.51	14.57	4.667*	81	0.525	69.15	80.26	63.82
S3 vs. S5	3.3	13.07	2.290**	81	0.253	61.79	88.08	57.4

Note. DM = difference of means, SD = standard deviation of difference, Inversion: R = Root, F = First, S = Second; Melody: 1 = Root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; % above mean indicates the percent of ratings for one level of a factor will be above the mean of medians of another level, % overlap indicates the percent of overlap between the distributions of the two levels, *P* superiority indicates the chance the rating of a random participant will agree with the findings of two-tailed *t*-test;*$p < .0056$, **$p < .05$.

Three-way Interactions

Inversion, Melody, and chord Quality

From Table 3.2 we find Inversion, Melody, and chord Quality interact affecting the level of perceived tension, $F(4,320) = 4.42$, $p < .002$. It seems the addition of chord Quality strengthens the effect of the Inversion* Melody interaction, while the effect size of Inversion*Quality is reduced slightly by the addition of Melody.[303] The nonparallel and crossing lines of Figure 3.10 illustrate the three-way interaction.

The Cohen's *d* results of paired samples *t*-tests (Table 3.7) show this effect, on participants' perception of tension, when chord Quality is added to the Inversion*Melody interaction. In general, regardless of Melody, the effect size for Root Major Quality chords is smaller than for Root minor Quality chords. In comparison, regardless of Melody, the effect size is larger for both First Inversion Major Quality and Second Inversion Major Quality than for their minor chord Quality parallels.

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[301] Because all the data was subjected to nine paired samples *t*-tests all at once, a Bonferroni correction could be applied. In this case, *p*-values < .0056 ($\alpha = .05/9$) would be considered significant.

[302] The values for % above mean, % overlap, and probability of superiority were calculated using the website www.rpsychologist.com/d3/cohend/ created by Kristoffer Magnusson. Magnusson's representation allows for only one decimal place for Cohen's *d*. Thus, both Cohen's *d* of .209 and .17 are entered as .2. While this means the values obtained using Magnusson's algorithm are close to but not exact interpretations of Cohen's *d*, the approximations are more useful than the small, medium, and large usual interpretations of Cohen's *d*.

[303] This is logical, as the main effect of Quality is large while the main effect of Melody is small. Thus, the addition of Quality to an interaction would have more influence on the perception of tension than would the addition of Melody.

Both Major Quality and minor Quality Root position chords, with Melody 1 and Melody 3, were perceived as embodying different levels of tension. The effect was larger for minor Quality chords (Cohen's *d* = .466, indicating approximately 80.26% overlap of the distributions, approximately 69.15% of ratings for minor_Root_Melody 1 are higher than those for minor_Root_Melody 3, and approximately 63.82% probability a randomly chosen participant would rate minor_Root_Melody 1 as tenser than minor_Root_Melody 3) than for Major Quality chords (Cohen's *d* = .270, indicating approximately 88.08% overlap of the distributions, approximately 61.79% of ratings for Major_Root_Melody 1 are higher than those for Major_Root_Melody 3, and approximately 58.4% probability a randomly chosen participant would rate Major_Root_Melody 1 as tenser than Major_Root_Melody 3).

The opposite was true for First Inversion chords with Melody 1 and Melody 3. The effect on Major Quality chords, (Cohen's *d* =.513, indicating approximately 80.26% overlap of the distributions, approximately 69.15% of ratings for Major_First Inversion_Melody 1 are higher than those for Major_First Inversion_Melody 3, and approximately 63.82% probability a randomly chosen participant would rate Major_First Inversion_Melody 1 as tenser than Major_First Inversion_Melody 3), was larger than was the effect on minor Quality chords (Cohen's *d* =.253, indicating approximately 88.08% overlap of the distributions, approximately 61.79% of ratings for minor_First Inversion_Melody 1 are higher than those for minor_First Inversion_Melody 3, and approximately 58.4% probability a randomly chosen participant would rate minor_First Inversion_Melody 1 as tenser than minor_First Inversion_Melody 3). Regardless of chord Quality, participants rated the difference in perceived tension between R3 and R5, and between F3 and F5, as small.

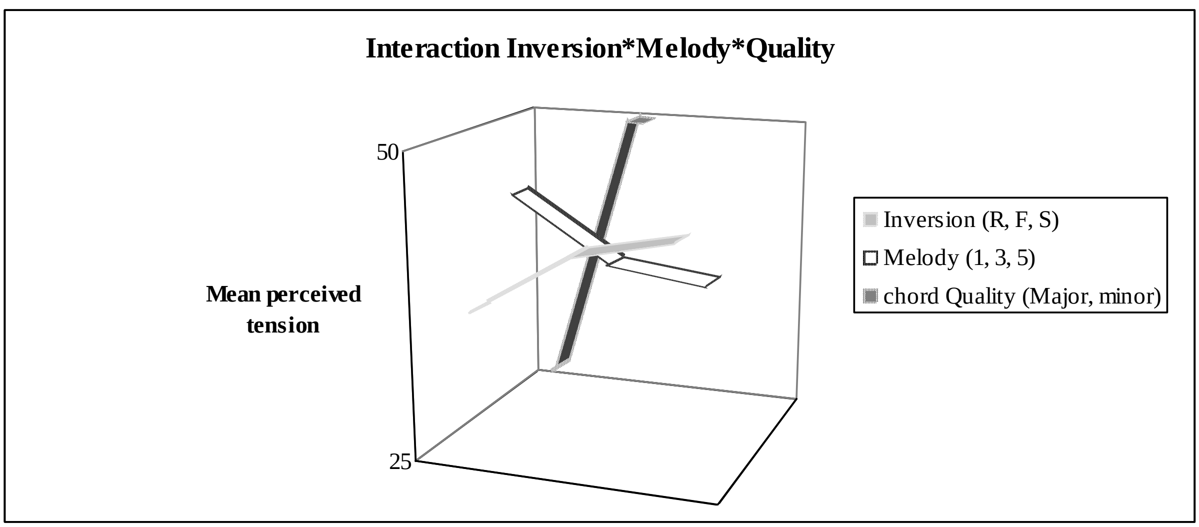

Figure 3.10. Interaction of Inversion (Root, First, Second), Melody (1, 3, 5), and chord Quality (Major, minor).

Chord Quality influenced the perception of tension for Second Inversion chords as, with the cases above, the difference perceived between S3M and S5M was small. In contrast, the perceived difference in tension between S3n and S5n was the largest for that Inversion. The graph at Figure 3.11 shows, other than Root position, effect sizes due to change in Inversion (First and Second) and Melody (1, 3, and 5) are larger for Major chord Qualities than for minor chord Qualities. Changes in Melody comparisons for Root position chords follow a similar pattern for Major and minor chord Qualities. The effect size, indicating the difference in perceived tension between Melody 1 and

Melody 5, for First and Second Inversion chords is greater for Major chord Qualities than for the same comparisons with minor chord Qualities.

Table 3.7.

Paired samples t-test (two-tailed) Inversion_Melody_Quality Interaction[304]

Pair	DM	SD	*t*	df	Cohen's *d*	% Above mean[305]	% Overlap	*P* Superiority
R1M vs. R3M	4.04	15.26	2.400**	81	0.270	61.79	88.08	58.4
R1M vs. R5M	1.59	14.27	1.006	81	0.114	53.98	96.01	52.82
R3M vs. R5M	-2.46	12.35	-1.802	81	-0.199	57.93	92.03	55.62
F1M vs. F3M	7.32	14.54	4.559*	81	0.513	69.15	80.26	63.82
F1M vs. F5M	10.73	14.92	6.513*	81	0.739	75.8	72.63	68.97
F3M vs. F5M	3.41	13.7	2.252**	81	0.249	61.79	88.08	58.4
S1M vs. S3M	6.51	22.84	2.581**	81	0.287	61.79	88.08	58.4
S1M vs. S5M	11.14	18.89	5.341*	81	0.613	72.57	76.42	66.43
S3M vs. S5M	4.63	17.8	2.355**	81	0.262	61.79	88.08	58.4
R1n vs. R3n	8.04	17.31	4.208*	81	0.466	69.15	80.26	63.82
R1n vs. R5n	6.55	16.14	3.677*	81	0.409	65.54	84.15	61.14
R3n vs. R5n	-1.49	14.65	-.919	81	-0.102	53.98	96.01	52.82
F1n vs. F3n	3.91	15.5	2.284**	81	0.253	61.79	88.08	58.4
F1n vs. F5n	4.4	17.95	2.221***	81	0.246	61.79	88.08	58.4
F3n vs. F5n	.49	16.52	.271	81	0.030	50	100	50
S1n vs. S3n	1.9	15.21	1.129	81	0.125	53.98	96.01	52.82
S1n vs. S5n	3.88	18.92	1.856	81	0.105	53.98	96.01	52.82
S3n vs. S5n	1.98	19.02	.943	81	0.205	57.93	92.03	55.62

Note. DM = difference of means, SD = standard deviation of difference, Inversion: R = Root, F = First, S = Second; Melody: 1 = Root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor; % above mean indicates the percent of ratings for one level of a factor will be above the mean of medians of another level, % overlap indicates the percent of overlap between the distributions of the two levels, *P* superiority indicates the chance the rating of a random participant will agree with the findings of two-tailed *t*-test; $^{*}p < .001$, $^{**}p < .0028$, $^{***}p < .05$.

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[304] Because all the data was subjected to 18 paired samples *t*-tests all at once, a Bonferroni correction could be applied. In this case, p-values < .0028 ($\alpha = .05/18$) would be considered significant.

[305] The values for % above mean, % overlap, and probability of superiority were calculated using the website www.rpsychologist.com/d3/cohend/ created by Kristoffer Magnusson. Magnusson's representation allows for only one decimal place for Cohen's *d*. Thus, both Cohen's *d* of .209 and .17 are entered as .2. While this means the values obtained using Magnusson's algorithm are close to but not exact interpretations of Cohen's *d*, the approximations are more useful than the small, medium, and large usual interpretations of Cohen's *d*.

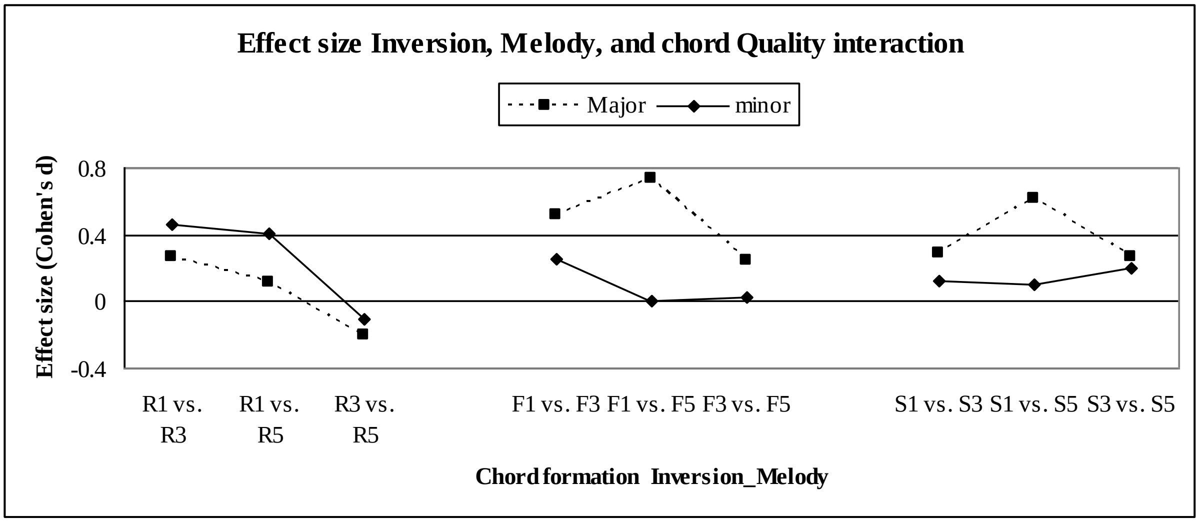

Figure 3.11. Interaction of Inversion (Root, First, Second), Melody (1, 3, 5), and chord Quality (Major, minor).

Inversion, chord Quality, and Expertise

The ANOVA results indicate there is an Inversion*Quality*Expertise interaction, $F(2, 80) = 4.32$, $p < .002$.[306] Figure 3.12 illustrates this interaction, as no line runs parallel to any other line. While there appears to be no main effect of Expertise in general, and Expertise does not appear to interact with either Inversion or Quality alone, it does appear Expertise interacts to a small degree ($\eta^2 = .0013$) with Inversion and Quality together, to affect listeners' perception of tension.

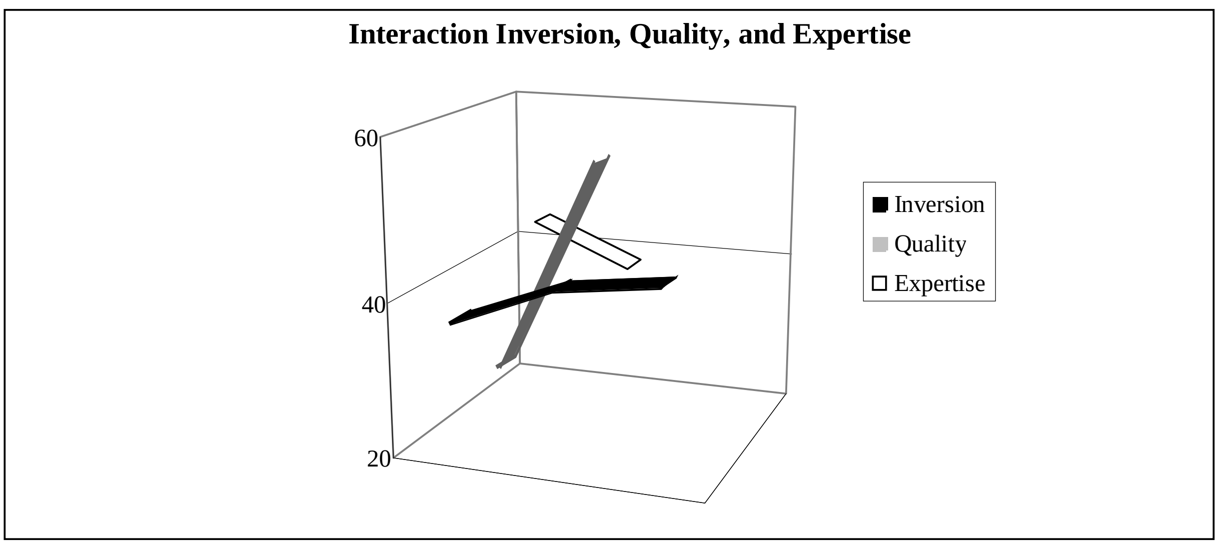

Figure 3.12. Interaction of Inversion (Root, First, Second), Quality (Major, minor), and Expertise (Novice, Expert).

Conclusions

The omnibus ANOVA demonstrates main effects and interactions are found in these data. Effect sizes (η^2) from this analysis indicate chord Quality had the largest effect on participants' perceived tension. The effect of

[306] When outliers are removed, the interaction of Inversion*Quality*Expertise is not significant. As explained in Appendix F, except for this interaction, the significance of all main effects and interactions remains the same for data analyses with and without outliers.

Inversion and Melody was small. Post hoc paired *t*-tests tease apart and give effect sizes (Cohen's *d*), for the 4 factors, the 10 levels of the factors, and their interactions. The results of the statistical tests reveal Lerdahl's *Surface Tension Rule* does not quantify adequately listeners' perception of tension embodied in four-note chords. Heard outside of a musical and tonal context, variations of the bass note (Inversion: Root, First, Second), soprano note (Melody 1, Melody 3, Melody5), and chord Quality (Major, minor) result in varying degrees of perceived surface tension. This study demonstrates variations in levels of perceived surface tension are due to these factors acting independently (main effects). This study also shows variations in levels of perceived surface tension are due, to a lesser degree, to the various combinations of the factors (interactions). This is true regardless of Expertise (as defined by this study as a combination of explicit and implicit learning).

Lerdahl's *Surface Tension Rule* quantifies tension due to the surface features of a chord and not tension due to its musical context. The *Surface Tension Rule* addresses only the main effects of Inversion and Melody. He assigns a tension added value of 0 to chords in Root position. For both First and Second Inversions, Lerdahl assigns a tension added value of 2. This study shows Second Inversion chords are heard as more tense than are First Inversion chords. Lerdahl does not differentiate between First and Second Inversion chords and adds a tension value of 2 for both. These results suggest tension added due to chords in First Inversion should have a smaller value than tension added due to chords in Second Inversion.

Lerdahl's *Surface Tension Rule* predicts chords with the root (1) in the Melody are less tense than are chords with either 3 or 5 in the Melody. The results of this study, contrary to Lerdahl's model of surface tension, indicate Melody 1 is perceived as tenser than Melody 3 or Melody 5. His added tension values of 1 for chords with either 3 or 5 in the Melody, and 0 for Melody 1, are not reflective of the results obtained by this study. The results of this study for the between-subjects factor Melody are not only contrary to Lerdahl's *Surface Tension Rule* but also to the tenets of music theory as well as previous research.[307] Reasons for these unexpected results are explored in Chapter 5.

As stated above, Lerdahl's *Surface Tension Rule* assigns a tension added value of 2 for First and Second Inversions. He assigns a tension added value of 1 for Melody 3 and Melody 5. He hypothesises Inversion has more effect on perceived tension than does Melody. The effect sizes (η^2 = .014 and .013 respectively) narrowly support his assertion.

Lerdahl's *Surface Tension Rule* does not address the effect of chord Quality. There is no tension added value assigned for chord Quality. The results of this study show this to be an important oversight as chord Quality alone accounts for a large proportion of participants' perception of tension in chord formations heard outside of a musical or tonal context. Regardless of Inversion and Melody, minor chords are perceived as conveying more tension than are Major chords. Outside of musical and tonal contexts, participants relied predominantly upon chord Quality to assign ratings for perceived tension. Within a musical and tonal context other musical characteristics (e.g. Inversion, Melody, melodic attraction, harmonic progression, voice leading) may dominate.

Supporting some of the results of the present study is one conducted by Lahdelma and Eerola in which they asked participants to rate tension, consonance, energy, preference and valence of triads (and their Inversions),

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[307] Recall from chapter 1, the reasoning of most music theorists referred primarily to chords heard in a musical context. The chords in this study were heard devoid of a musical context.

various tetrachords (not Major or minor), pentachords, and hexachords heard outside of a musical or tonal context.[308, 309] Like the results for the Major and minor tetrachords in the present study, Lahdelma and Eerola found, regardless of Inversion, Major triads were perceived as less tense than were minor triads. Also like tetrachords in the present study, regardless of chord Quality, Root position triads were perceived as less tense than First Inversion triads which were perceived as less tense than Second Inversion triads. Lahdelma and Eerola found, when combining the results from all the chords heard in their experiment, tension correlated positively with energy and negatively with consonance. This is partly true for Major and minor triads. Regardless of triad Quality, Root position had lower energy ratings and lower tension ratings; both energy and tension ratings were higher for First Inversion, and higher again for Second Inversion. However, regardless of Inversion, minor triads were perceived as more tense but with lower energy ratings than Major triads.

Defining Expertise in studies of music perception can be difficult. Participants in this study were identified as Novice or Experts based on a combination of levels of music education and experience. However, no effect of Expertise was found so the data were collapsed across Expertise. This was true even though participants reported studying a variety of instruments, with a large range in levels of training, and of proficiency, as well as of time spent actively and passively listening to Western tonal music. Lahdelma and Eerola found no effect of Expertise among 418 participants, of varying levels of musical sophistication, in their ratings of perceived tension in Major and minor triads and their inversions. Lahdelma and Eerola report, "both musicians and nonmusicians distinguished between the triadic inversions on the dimensions of energy, tension, and consonance or dissonance similarly."

Lerdahl chooses not to define the characteristics of listeners whose perception of tension is predicted by his model of tonal pitch space. Instead, explaining the assumptions made by his model of tonal pitch space (based on Lerdahl and Jackendoff's 1983 book *A Generative Theory of Tonal Music* or GTTM), Lerdahl says, "GTTM assumes an 'experienced listener'."[310] This study shows listeners, across a wide range of Expertise of Western tonal music, perceive surface tension in four-note chords—varying in Inversion, Melody, and chord Quality, and heard in the absence of a tonal context—in a similar manner.

[308] Imre Lahdelma and Tuomas Eerola, "Mild Dissonance Preferred Over Consonance in Single Chord Perception," *i-Perception* (May-June 2016): 9. DOI: 10.1177/2041669516655812.

[309] Like the present study, Lahdelma and Eerola required participants to rate perceived tension of chords heard outside a musical or tonal context. However, the Lahdelma and Eerola study differs from the present study in at least two significant ways. Firstly, participants rated perceived tension in triads rather than tetrads. As all triads were in close position, both the lowest and highest notes changed for each chord position. In this way, Root position chords always had the root on the bottom and the fifth on the top. First inversion chords always had the third on the bottom and the root on the top. Second inversion chords always had the fifth on the bottom and the third on the top. The tetrads used in the current study allowed for each bass note to have three different melody notes, and each melody note to have three different bass notes. Secondly, the present study required all participants, regardless of level of Expertise, to assign a perceived tension value in 2s. Lahdelma and Eerola allowed participants to listen to each chord formation as many times as they wanted before giving their rating. Lahdelma and Eerola report no difference in ratings due to Expertise but do not report how many times Experts and Novices listened before recording their ratings. Lahdelma and Eerola's theory of the effect of chord sharpness in determining musical tension is discussed in Chapter 5.

[310] Lerdahl (2001), 5.

CHAPTER 4: AN ALTERNATIVE ANALYSIS USING CONFIDENCE INTERVALS

Introduction

Analysis of Variance (ANOVA) and paired samples *t*-tests performed on the data from this study showed no effect of Expertise, but a strong effect of chord Quality on participants' perception of tension embodied in chords heard out of a musical or tonal context.[311, 312] These same analyses revealed Melody, Inversion, and the interactions among the 3 within-subjects factors had much less effect upon participant's perception of tension in this study. Yet, the effect of Inversion and Melody are deemed important by music theorists, composers, performers, and by Lerdahl's *Surface Tension Rule*.

The results of both ANOVA and paired samples *t*-tests are based upon null hypothesis significance testing (NHST). There is some concern regarding the reliability of NHST and the meaningfulness of the results.[313] Among the concerns of Cumming and others is ignoring data because statistical analyses returned *p* values greater than .05.[314] Reliability of results when studies are replicated is another issue.[315] Cumming and Finch believe Confidence Intervals (CIs) offer greater reliability than does NHST.[316] Among Cumming's *Twenty-five Guidelines for Improving Psychological Research* are the following: "7. Whenever possible, adopt estimation thinking and avoid dichotomous thinking ... 9. Do not trust any *p* value ... 11. Move beyond NHST and use the most appropriate methods, whether estimations or other approaches."[317] Cumming recommends using Effect Size (ES) coupled with Confidence Intervals as they are "much more informative because [they indicate] the extent of uncertainty, in addition to providing the best point estimate of what we want to know."[318] Loftus and Masson agree, asserting "at the very least, plotting a set of sample means along with their confidence intervals can provide an initial, rough-and-ready, intuitive assessment of (1) the best estimate of the underlying pattern of population means,[319] and (2) the degree to which the observed pattern of sample means should be taken seriously as a reflection of the underlying pattern of population means, that is, the degree of statistical *power*."[320]

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[311] The upper case letters for the words Inversion, Melody, chord Quality, and Expertise identify them as the four factors in the study. Similarly, upper case letters for Root, First, Second, and Major identify them as levels of factors in this study. While minor is also a level in this study, it begins with a lower case letter following the tradition of identifying minor chords and regions with lower case letters.
[312] See Appendix D for an explanation of the statistical terminology and statistical procedures.
[313] See Geoff Cumming (2013). Also Geoffrey Loftus & Michael Masson (1994).
[314] For example, the results of the paired samples *t*-test reported in Table 3.3 suggest participants did not perceive a difference in tension between chords with the third in the Melody (Melody 3) and chords with the fifth in the Melody (Melody 5) because $p > .05$. How confident are we of this conclusion if $p = .051$ or $p = .049$?
[315] Cumming (2013) describes what he terms the dance of the *p* values and the dance of the CIs. Cumming demonstrates the relative reliability of 95% CIs over *p* values by running 25 simulations ($n = 32$) of an experiment with two independent variables. The first finding is *p* values range from .001 to .75. When considering the means of each subsequent simulation, 83.3% of 95% CIs contain the mean of the next experiment while only 38% match the same level of significance of the experiment following. (pp. 6-7)
[316] For a complete explanation, see Cumming 2013.
[317] Cumming (2013), 2.
[318] Cumming (2013), 7.
[319] Figure 4.4 graphically depicts the difference between the means of medians between Melody 3 and Melody 5 (of Table 3.3). We can see the difference between the means of the medians is small. The small range of the Confidence Intervals around this difference graphically depicts the reliability of the conclusion participants did not perceive tension due to Melody 3 to be much different from the tension perceived due to Melody 5.
[320] Loftus and Masson (1994), 478. Italics in original.

In addition to the concerns of Cumming and others, is the matter regarding performing Analysis of Variance and paired sample *t*-tests on skewed data such as resulted from this study. While scholarly support exists for accepting the results obtained from these statistical tests on skewed data, an alternate method was sought to examine these data. For this reason, the data were re-analysed for main effects and interactions by calculating Effect Sizes and 95% Confidence Intervals.

With a repeated measures design like this study, Effect Size is quantified by finding the difference between the means (or means of the medians as is the case of this present study) of the factors or levels under consideration. The larger the difference between the means, the greater the size of the effect. Confidence Intervals, equal to Margins of Error (MOE) above and below the difference of the means, may be interpreted in several ways. First, when the difference of the means is found within a particular CI, it means there is a high degree of certainty (95%) the interval contains the difference between means for the population (estimated by the difference between the sample means) of listeners familiar with Western tonal music.[321] The length of a CI is inversely related to correlation, where longer CIs indicate a weaker correlation and shorter CIs denote a stronger correlation. The length of the CI may also be interpreted as an indication of the level of precision or sensitivity with a shorter CI indicating a more precise and sensitive design. Below is a discussion of the results when the data from this study are analysed using Effect Size and 95% Confidence Intervals.

Results and Discussion

Expertise

We noted from Figure 3.3 (Means of median perceived tension by Expertise, by chord formation), participants identified as Novice rated all chord formations as more tense than did Expert participants for the same chord formations. Also evident was the similar trend in perceived tension between Novice and Expert participants across chord formations. Figures 4.1 and 4.2 show the same data with 95% CIs separated by chord Quality, facilitating analysis.[322]

Because unlike Inversion, Melody, and chord Quality, Expertise is a between-subjects factor in this study, a comparison by Expertise between CIs around each mean of median for each chord formation can be made. We can see, regardless of Expertise, the CIs for Major Quality chords in Figure 4.1 are around the same length signifying equal precision for each chord formation.[323] We can be 95% certain the population mean (estimated by the sample mean) is within the range of values found between the lower and upper limits of the CI. Other than R1 and F5, the CIs for each Major chord formation overlap to varying degrees. Overlapping CIs bring the sample means of Expert and Novice closer together, thus negating the effect of Expertise. Expertise, then, appears to affect perception of tension of Major chord formations for R1 and F5 only.

[321] A Confidence Interval of 95% tells us if we were to repeat the same experiment 100 times, we would expect the means of medians to fall within the interval 95 out of 100 times, i.e., we could also expect the mean of medians would be outside of the interval 5 out of 100 times.
[322] See Appendix G for tables of data for all figures in this chapter. Numbers correspond such that, for example, Table G.4 presents the data for *Figure* 4.4.
[323] The Margin of Error (MOE) is half the length of the Confidence Interval represented by the error bars. The error bars indicate the MOE above and below the sample mean.

We find pretty much the same situation for the effect of Expertise in the perception of tension in minor Quality chords. Generally, CIs in Figure 4.2 for Experts are longer than are those for Novices, suggesting Experts were less unified than were Novices in their perception of tension.[324] The CIs for Experts are somewhat longer for minor Quality chords than for Major Quality chords, indicating a greater degree of variability. For Novices, the CIs for minor Quality chords are somewhat shorter than for Major Quality chords, indicating less variability. We can be 95% certain the population mean is within the range of values found between the lower and upper limits of the CIs. All the CIs for each chord formation overlap to varying degrees, once again bringing the sample means of Expert and Novice closer together, thus negating the effect of Expertise. Minimum overlap occurs for R1, S1, and S5; maximum overlap occurs for F3, F5, and S3, indicating good agreement, overall, between levels of Expertise. Expertise, then, appears to have little affect on the perception of tension for minor Quality chords.[325]

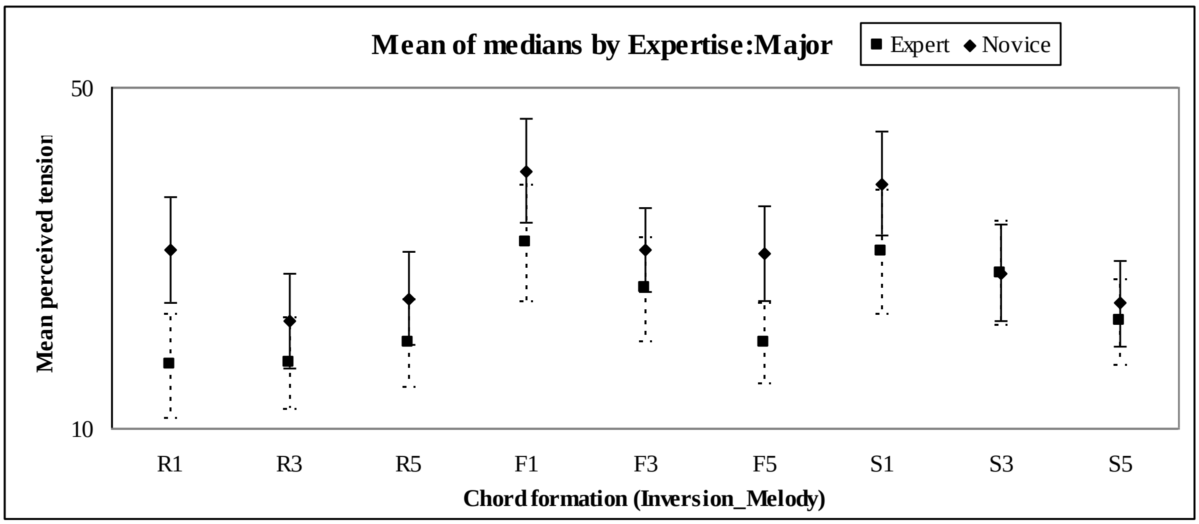

Figure 4.1. Means of median perceived tension for Major chord formations and 95% Confidence Intervals. (Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice).

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[324] As mentioned in Chapter 3, participants were encouraged to use the full range of the rating scale while judging Major and minor chords. Some Experts, with their awareness of and experience with higher tension chords like vii^{o7} and Augmented 6ths found it struggled to use the full range of the rating scale for Major and minor chords. Novices had no such difficulty. I believe this may explain the larger CIs for Experts than for Novices.

[325] The graphic representations of Effect Size and 95% Confidence Intervals for effect of Expertise on perception of tension due to chord Quality support the ANOVA results found in Table 3.2.

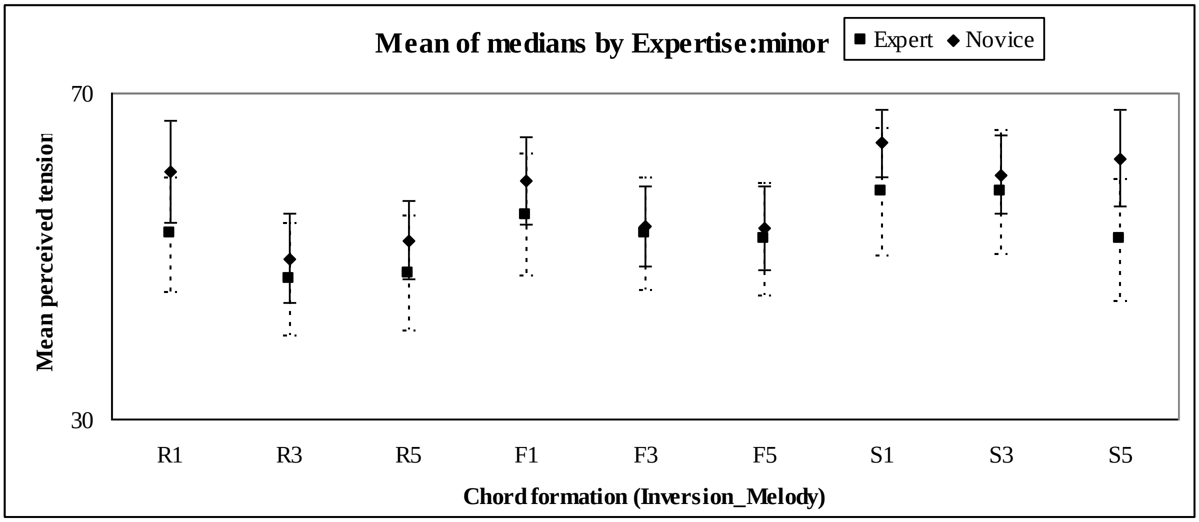

Figure 4.2. Means of median perceived tension for minor chord formations and 95% Confidence Intervals. (Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice).

Inversion

Inversion, Melody, and chord Quality are within-subjects factors in this study. Thus, the difference of the means of median perceived tension and the CIs on these differences are calculated.[326] Looking at Figure 4.3, we can see there is an effect of Inversion upon participants' perception of chord tension, as none of the differences between means of medians is zero. Also, none of the CIs include a value of zero. The value of the difference between the means of medians show participants heard a greater difference in tension between Root and Second Inversion chords; less so between Root and First Inversion; even less between First and Second Inversion. The length of the CIs indicates perceived tension between First and Second Inversion correlate most strongly. The CIs for the differences between Root and First Inversion, and between Root and Second Inversion are somewhat larger indicating a weaker correlation. These results support the findings of the paired samples *t*-test reported in Table 3.3, particularly the values for Cohen's *d*. These results also align well with Lerdahl's *Surface Tension Rule* in which he advises assigning an equal tension added value for First and Second Inversion chords. He also separates perceived tension due to Root position chords from that of First and Second Inversion chords.

[326] For Effect Sizes with between subjects (like Expertise) you can look at the overlap of Confidence Intervals. For within subjects (like Inversion, Melody, chord Quality) you have to look at difference of means and Confidence Intervals surrounding that difference.

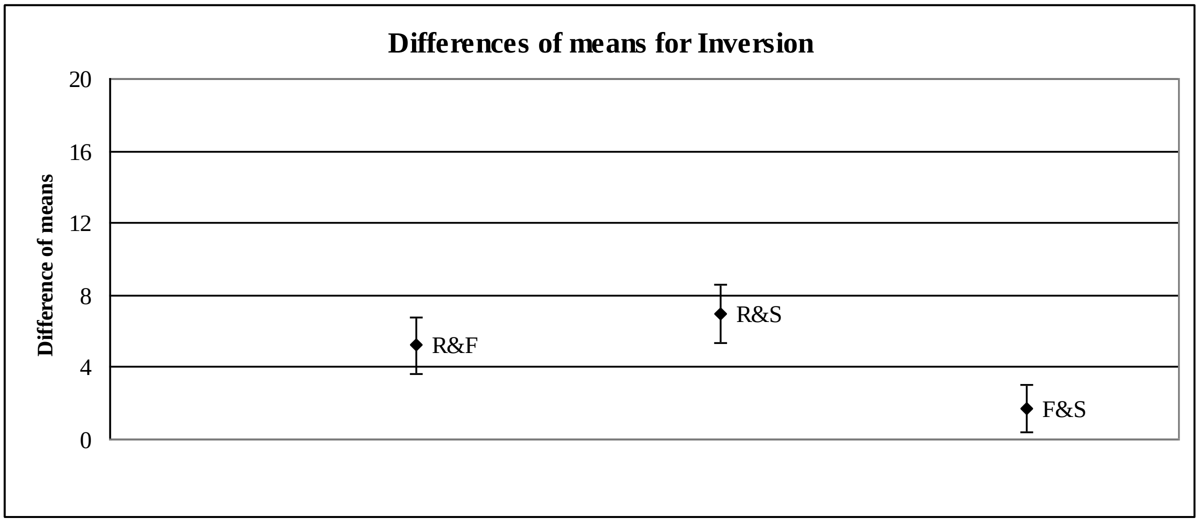

Figure 4.3. The difference means of median perceived tension and 95% Confidence Intervals for Inversion, where R = Root, F = First Inversion, and S = Second Inversion.

Melody

Lerdahl's *Surface Tension Rule* suggests an equal tension added value for Melody 3 and Melody 5, and none for Melody 1. The results in Figure 4.4 seem to confirm this directive. None of the difference of means of median perceived tension equal zero, indicating an effect of Melody on participants' perception of tension in the four-note chords of this study. The largest ES is found between Melody 1 and Melody 5, followed by Melody 1 and Melody 3. The difference of perceived tension between Melody 3 and Melody 5 is smaller.

The somewhat larger CIs for the difference of means of median perceived tension between Melody 1 and Melody 3, and between Melody 1 and Melody 5 suggest a weaker correlation between the sample means. The smaller CI around the difference of the means of median perceived tension between Melody 3 and Melody 5 indicate a stronger correlation. It is important to note, however, this CI crosses the x-axis at zero suggesting the possibility of finding no difference between the means of medians for Melody 3 and Melody 5. A value of zero, however, is less likely to occur than the value determined by this study, as the plausibility of a value decreases as you move towards the lower and upper extremes of the CI. These results support the results for the paired samples *t*-test and Cohen's *d* reported in Table 3.3 as well as Lerdahl's directive to place Melody 3 and Melody 5 into the same category, adding a value of 1 for both.

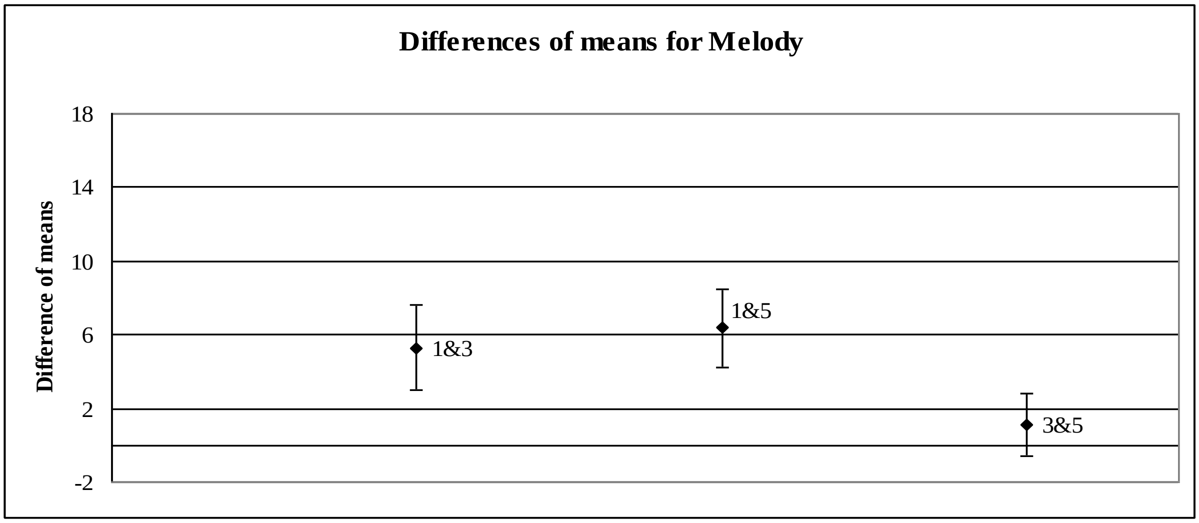

Figure 4.4. Difference of means of median perceived tension and 95% Confidence Intervals for Melody where, 1 = Root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

Chord Quality

Lerdahl does not include a tension added value for chord Quality in his *Surface Tension Rule*. The graph in Figure 4.5 suggests he should. The ES of chord Quality is 27.95—by far the largest Effect Size obtained from these data. For the participants in this study, chord Quality played an important role in the perception of tension embodied in four-note chords heard out of a musical and tonal context.

Puzzling, at first, is how to interpret the size of the CI around the difference of means of median perceived tension for chord Quality. Recall, the size of the CI is inversely related to the correlation between the two means. The smaller the CI, the stronger the correlation between the two independent variables. We know from Figure 3.2, minor Quality chords are perceived as tenser than their parallel Inversion_Melody Major Quality chords. However, it appears the general trend (by Inversion_Melody) is the same for each Quality. In fact, the correlation coefficient (*r*) for this comparison is .412. The positive value indicates one would expect a high perceived tension value for one Inversion_Melody_Major Quality chord formation if there was a high perceived tension for the minor Quality chord with the same Inversion_Melody formation. The opposite is also true—one would expect a low perceived tension value for one Inversion_Melody_Major Quality chord formation if there was a low perceived tension for the minor Quality chord with the same Inversion_Melody formation. The numerical value of the coefficient suggests this is a relationship of medium strength. The same interpretation applies to the size of the CI for chord Quality—that is, due to the lack of strong correlation, we can be reasonably certain the difference between the means of median perceived tension for Major and minor Quality chords is due to chord Quality. To put it another way, there is an effect due to chord Quality, of perceived tension when heard out of a musical and tonal context by listeners familiar with Western tonal music. This interpretation supports the results of the paired samples *t*-test and Cohen's *d* reported in Table 3.3.

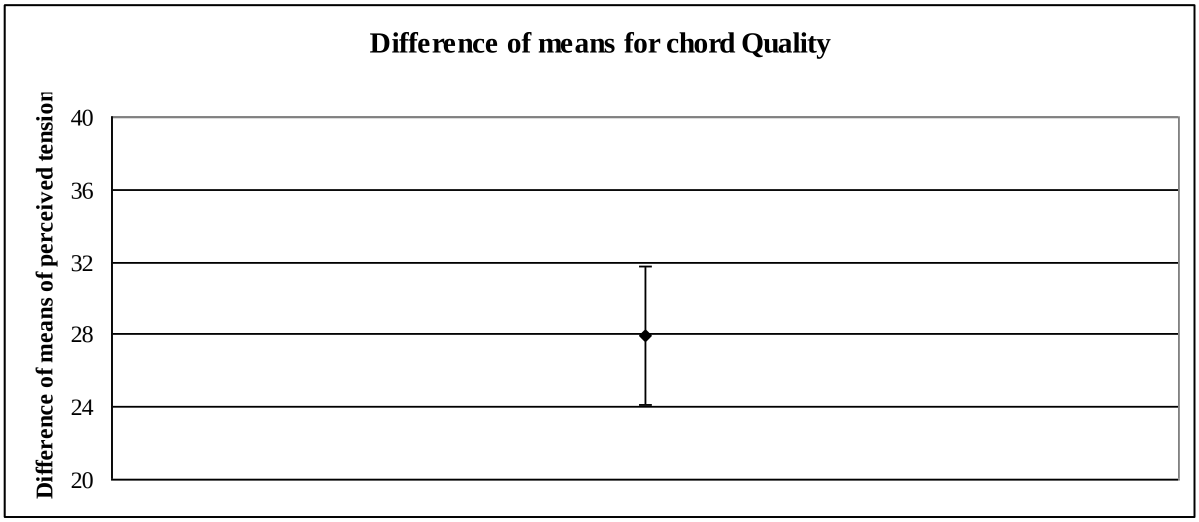

Figure 4.5. Difference of means of median perceived tension by chord Quality and 95% Confidence Interval.

Interaction of Inversion and Chord Quality

Major Quality

For music theorists, composers, and performers, the effect of Inversion is an important element in conveying musical instability/tension/emotion. From Figure 4.3, we observed an effect of Inversion upon participants' perception of chord tension in this study, with a greater difference in perceived tension between Root and Second Inversion chords; less so between Root and First Inversion; even less between First and Second Inversion. Since the effect of chord Quality overshadows the effect of Inversion and of Melody, differences between means of median perceived tension and corresponding CIs, for Inversion and for Melody, were calculated separately for chords of both Quality. Figures 4.6 and 4.7 show the results for Inversion, by chord Quality. Results for difference of means between Inversions for combined chord Quality, Major chord Quality, and minor Quality chords, along with their respective MOEs, are summarized below in Table 4.1.

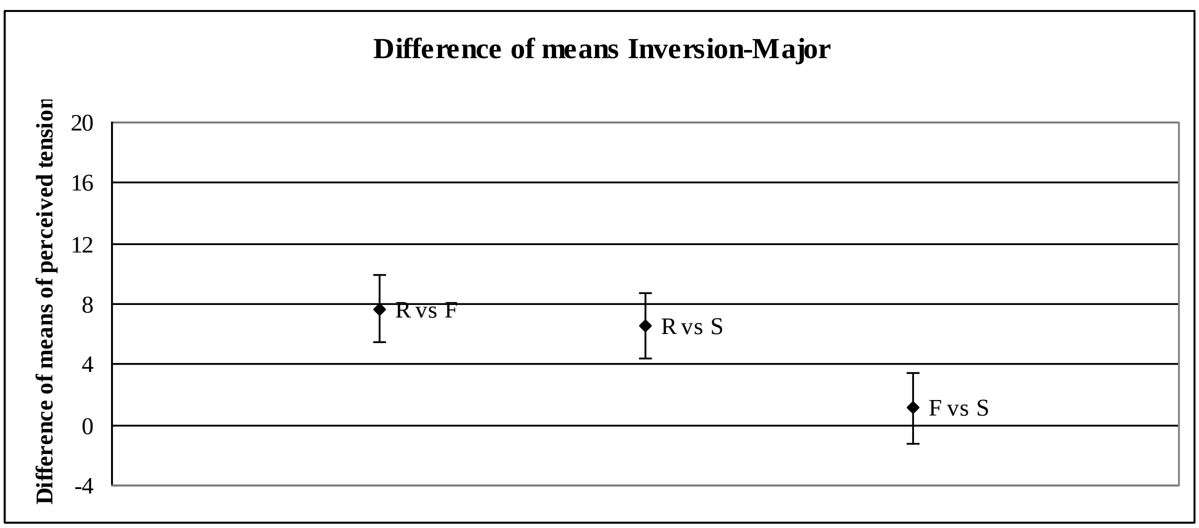

Figure 4.6. Difference of means of median perceived tension by Inversion and Major chord Quality with 95% Confidence Intervals where, R = Root, F = First Inversion, and S = Second Inversion.

The magnitude of differences between means of median perceived tension (ESs), when considering only Major Quality chords, are near the same as those found when considering all chord Qualities.[327] The order of ESs, (Root & First > Root & Second > First & Second) for Major chord Quality is not the same as for combined chord Quality (Root & Second > Root & First > First & Second). However, these findings support the results of the paired samples *t*-test and Cohen's *d* reported in Table 3.5 as well as Lerdahl's theory that tension due to Root position chords is different from that of either First or Second Inversion chords, and the difference of perceived tension between First and Second Inversion chords is small. The *Surface Tension Rule* suggests adding a value of 2 for both First and Second Inversion chords. These results indicate participants perceived similar amounts of tension for First and Second Inversion Major chords.

Also supporting the results of the paired samples *t*-test and Cohen's *d* reported in Table 3.5 and Lerdahl's equal tension added values for chords in First and Second Inversion are the lengths of the CIs. The small CI for the difference of means of median perceived tension (ES) between First and Second Inversions indicates a strong correlation between the ratings of perceived tension. As illustrated by the length of the remaining CIs, First and Second Inversion correlate less strongly with Root position. This indicates perceived tension for First and Second Inversions is similar. However, unlike the CIs combined chord Quality, the CI for the difference between the means of median perceived tension for First and Second Inversion Major Quality chords crosses the x-axis at zero. This indicates it is reasonable to assume the possibility listeners familiar with Western tonal music, upon hearing Major four-note chords out of a musical and tonal context, could hear no difference in tension between First and Second Inversion. It is somewhat likely listeners would perceive no difference in tension between First and Second Inversions, as the difference between means of median perceived tension value of zero, is towards the middle i.e., far away from the extremes of the lower and upper limits of the CI.

minor Quality

The ES of Root and Second Inversions of minor Quality chords is generally of the same magnitude as Root and Second Inversions for both Major and combined Quality chords. Once again, the order of ESs (Root & Second > First & Second > Root & First) is different from that of combined chord Quality, and from Major chord Quality. The ES for the comparison between Root and First is smaller for minor Quality chords alone than for either combined or Major Quality chords. These findings support the results of the paired samples *t*-test and Cohen's *d* reported in Table 3.5. The ES for the comparison between First and Second is larger for minor Quality chords alone than for either combined or Major Quality chords. This suggests an interaction between Inversion and minor chord Quality, such that participants perceived little difference in tension between Root and First Inversion, and a greater difference between First and Second Inversions. These differences between means of median perceived tension suggest there should be a tension added value for Second Inversion minor Quality chords, but not for First Inversion minor Quality chords. This is not accounted for in Lerdahl's *Surface Tension Rule* which suggests the least difference should be between First and Second Inversion.[328]

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[327] The difference between means of median perceived tension for Root and First Inversion Major chord Quality is somewhat larger than the same comparison for combined chord Quality.
[328] Table 3.2 indicates an interaction between Inversion and chord Quality.

The strength of the correlations, for the interaction of Inversion and minor Quality chords, are generally of the same magnitude. None of the CIs for minor Quality chords crosses the x-axis at zero. This indicates it is reasonable to assume there is an interaction between minor Quality chords and Inversion.

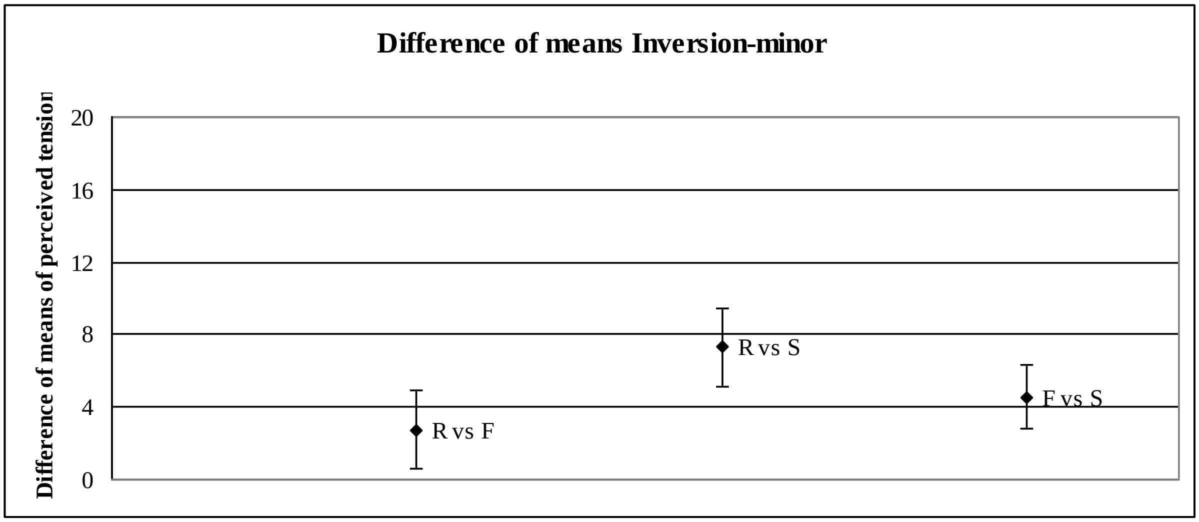

Figure 4.7. Difference of means of median perceived tension by Inversion and minor chord Quality with 95% Confidence Intervals, where R = Root, F = First Inversion, and S = Second Inversion.

The graph at Figure 4.3 suggests an effect of Inversion on participants' perception of tension in four-note chords heard out of a musical and tonal context. When separated by chord Quality, it appears the interaction is driven more by minor Quality chords than Major Quality chords. The results of difference of means of median perceived tension suggest Lerdahl's equal tension added values for First and Second Inversions is not correct for minor Quality four-note chords heard out of a musical and tonal context.

Table 4.1.

Data table summarising the effect of Inversion for combined chord Quality, Major chord Quality, and minor Quality chords

Inversion	Diff. of means: Combined	MOE	Diff. of means: Major	MOE	Diff. of means: minor	MOE
R & F	5.2236	1.5704	7.6931	2.272	2.7541	2.1832
R & S	6.936	1.6	6.5589	2.196	7.313	2.1587
F & S	1.7124	1.3456	1.1341	2.326	4.5589	1.7491

Note: Inversion: R = Root, F = First, S = Second; Diff. of means = Difference of means of median perceived tension; MOE = Margin of Error. The length of the 95% Confidence Intervals (CIs) is twice the Margin of Error.

Interaction of Melody and chord Quality

Major Quality

From Figure 4.4, we concluded participants perceived little difference in tension between chords, heard out of a musical and tonal context, and containing either the third (M3) or the fifth (M5) in the Melody. This conclusion aligns with Lerdahl's *Surface Tension Rule*. We also found, from Figures 4.3, 4.6, and 4.7, chord Quality interacted with Inversion, where Inversion has more effect upon perception of tension in minor Quality chords than in Major Quality chords. Figures 4.8 and 4.9 show a similar, if opposite, interaction of Melody and chord Quality. Analysis of

Variance (ANOVA) returned $p > .05$, suggesting the lack of interaction between Melody and chord Quality (Table 3.2). Results for differences of means of median perceived tension between Melody for combined, Major, and minor Quality chords along with their respective MOEs are summarized below in Table 4.2.

With combined chord Quality, ES was largest for the difference between Melody 1 and Melody 5, followed by between Melody 1 and Melody 3, and between Melody 3 and Melody 5. We find the same order when considering the interaction of Melody and Major Quality chords, although the magnitude of the effect is larger when considering Major Quality chords alone. These results align with Lerdahl's equal tension added values for Melody 3 and Melody 5.

The lengths of the CIs, of a similar magnitude to combined chord Quality, show a stronger correlation between Melody 1 and Melody 5 than between Melody 1 and Melody 3. Once again, the CI for the difference of means of medians between Melody 3 and Melody 5 crosses the x-axis at zero, suggesting the possibility of finding no difference between these means. The possibility of a value of zero is less likely to occur than is the sample mean since zero is found at the lower limit of the CI. These results of the interaction between Melody and chord Major Quality support an equal tension added value for Melody 3 and Melody 5 as directed in Lerdahl's *Surface Tension Rule*.

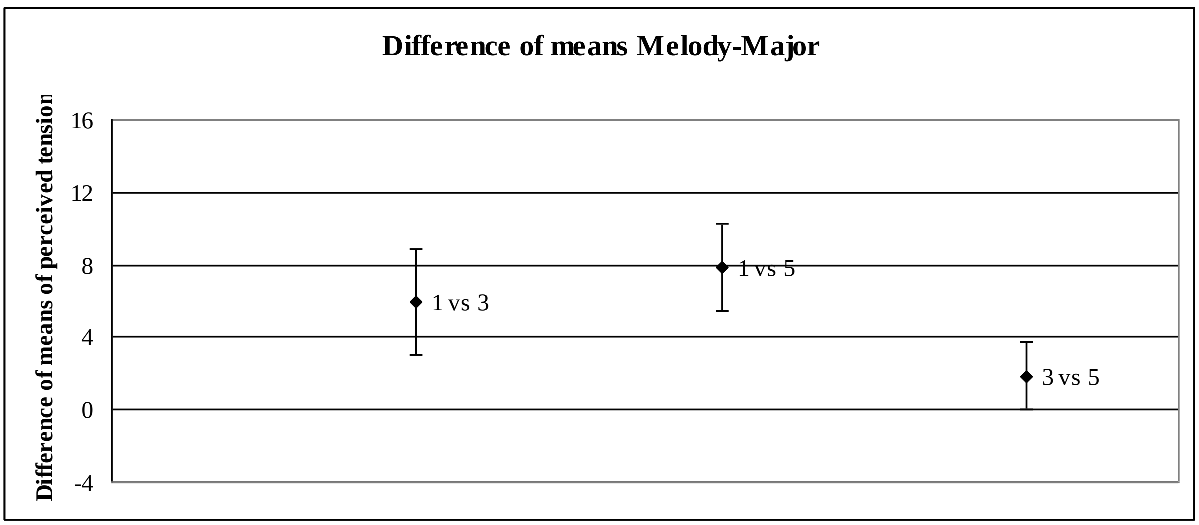

Figure 4.8. Difference of means of median perceived tension and 95% Confidence Intervals for Melody in Major Quality chords, where 1 = Root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

minor Quality

The results of the interaction of Melody with minor Quality chords (Figure 4.9) are similar to those of the combined Quality and Major Quality chords. With combined chord Quality, the ES was largest for the difference between Melody 1 and Melody 5, followed by Melody 1 and Melody 3, and Melody 3 and Melody 5. We find the same order when considering the interaction between Melody and minor Quality chords, even though the magnitude of the effect is smaller when considering minor Quality chords alone. This suggests participants' perception of tension is less affected by variations in Melody for minor Quality chords than for Major Quality chords.

The CIs are generally of the same overall range of magnitude as those of the combined Quality and Major Quality chords. However, the strength of the correlations is different for each pair of comparisons. With combined

Quality chords and Major Quality chords, the comparison between Melody 3 and Melody 5 correlated most strongly, followed by the difference between Melody 1 and Melody 5, and the difference between Melody 1 and Melody 3. With minor Quality chords, the strongest correlation was between Melody 1 and Melody 3, followed by Melody 3 and Melody 5, and Melody 1 and Melody 5. However, as before, the CI for the difference of means of median perceived tension between Melody 3 and Melody 5 crosses the x-axis at zero suggesting the possibility of finding no difference between these means. It is quite likely listeners could perceive no difference in tension between Melody 3 and Melody 5 in minor Quality chords as the value of zero is quite near the middle of the CI. These results also support an equal tension added value for Melody 3 and Melody 5 as directed in Lerdahl's *Surface Tension Rule*. The magnitude of the ES suggests a smaller tension added value than that used for the interaction of Melody and Major Quality chords, is appropriate for the interaction of Melody and minor Quality chords.

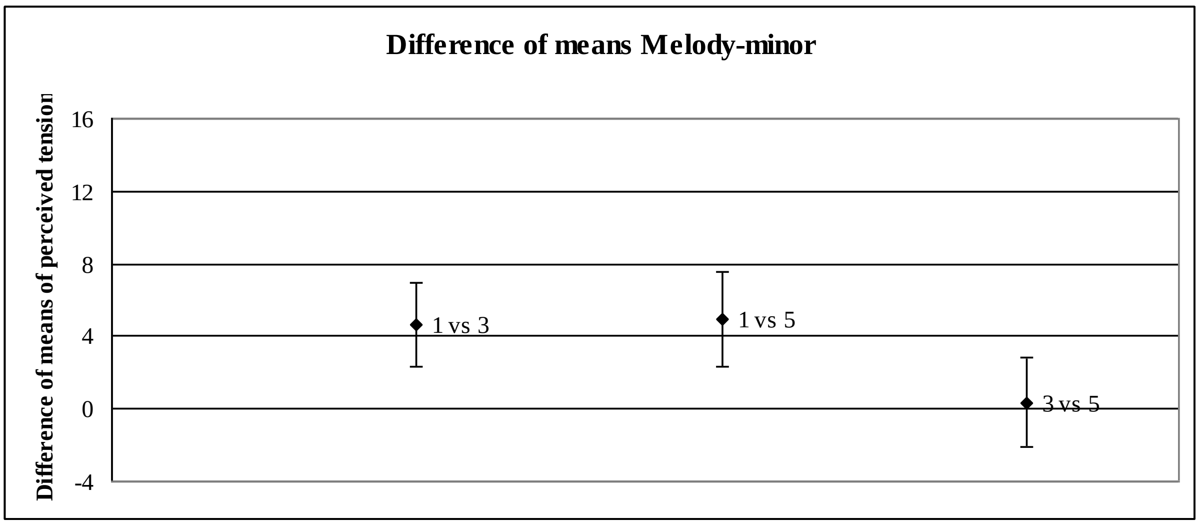

Figure 4.9. Difference of means of median perceived tension and 95% Confidence Intervals for Melody in minor Quality chords, where 1 = Root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

Table 4.2.

Data table summarising the effect of Melody for combined chord Quality, Major chord Quality, and minor Quality chords

Melody	Diff. of means: Combined	MOE	Diff. of means: Major	MOE	Diff. of means: minor	MOE
1 & 3	5.2876	2.299	5.9593	2.906	4.6159	2.309
1 & 5	6.3821	2.131	7.8191	2.414	4.9451	2.66
3 & 5	1.0945	1.696	1.8598	1.885	0.3293	2.46

Note: Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error.

Interaction of Melody and Expertise

From Figures 4.1 and 4.2, we determined Expertise had little effect upon participants' perception of tension in four-note chords heard in isolation. The ESs in Figure 4.10 suggest Expertise plays a role in the perception of tension when 1 or 5 are in the Melody. Expertise has less influence when 3 is in the Melody. The 95% CI around

Melody 3 crosses the x-axis at zero suggesting it is possible Expertise plays no part in the perception of tension, when 3 is in the Melody, for listeners familiar with Western tonal music. Since the value of zero occurs towards the lower extreme of the CI, the possibility of no effect of Expertise is more remote than the small effect revealed by the ES. This interpretation supports the results of the paired samples *t*-test and Cohen's *d* reported in Table 3.4.

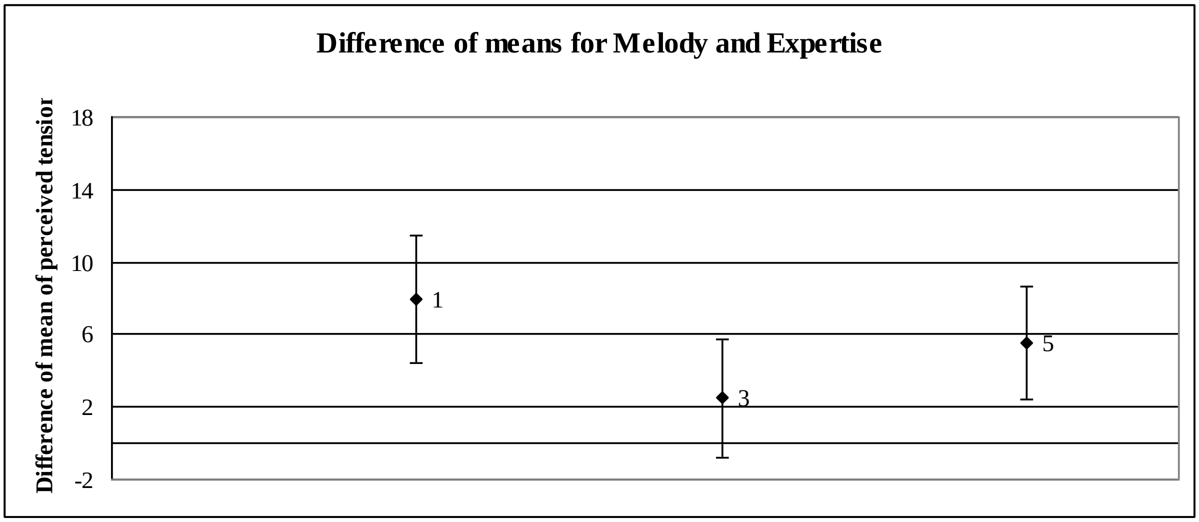

Figure 4.10. Difference of means of median perceived tension and 95% Confidence Intervals for the interaction of Melody and Expertise, where 1 = Root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

Interaction of Inversion and Melody

We know from Figures 4.4, 4.8, 4.9, and 4.10, participants perceived little differences in tension, regardless of chord Quality, between Melody 3 and Melody 5. From Figures 4.3, 4.6, and 4.7 participants perceived little difference in tension between First and Second Inversion Major Quality chords and between Root and First Inversion minor Quality chords. The ESs in Figure 4.11 show, with combined chord Quality, regardless of Inversion, chords with Melody 3 and Melody 5 are perceived as similar in embodied tension. As illustrated by the 95% CIs crossing the x-axis at zero, it is remotely possible listeners would perceive no difference between Root position chords with Melody 3 and Melody5, and First Inversion with Melody 3 and Melody 5. This interpretation supports the results of the paired samples *t*-test and Cohen's *d* reported in Table 3.6.

Inversion interacts with Melody 1 and Melody 5 as a larger ES occurs for First and Second Inversions than for Root position chords. The ES between Melody 1 and Melody 3 decreases as the chord position becomes more unstable and more tense i.e., Root is more stable than is First Inversion which is more stable than Second Inversion.

The 95% CIs for all Inversion*Melody comparisons are of the same general magnitude. The strongest correlation (shortest CI) is between Root position Melody 3 and Root position Melody 5. The weakest correlation (longer CI) is between Second Inversion Melody 1 and Second Inversion Melody 3. This interpretation supports the results of the paired samples *t*-test and Cohen's *d* reported in Table 3.6.

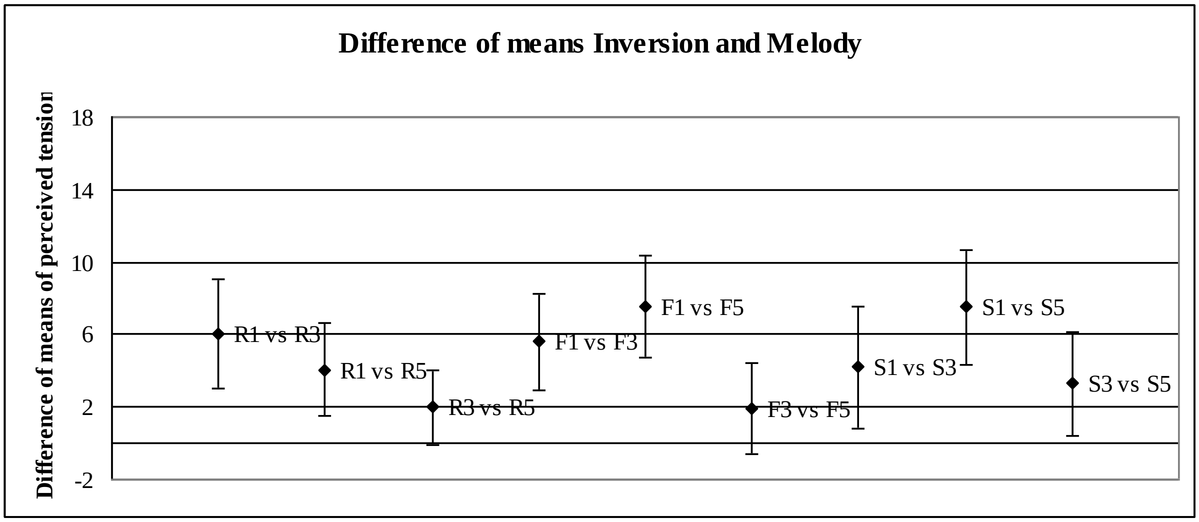

Figure 4.11. Difference of means of median perceived tension and 95% Confidence Intervals for the interaction of Inversion and Melody, where Inversion: R = Root, F = First, S = Second; Melody: 1 = Root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

Conclusions

This chapter re-examines the main effects and most of the interactions tested with ANOVA and paired sample *t*-tests (chapter 3). Considering Effect Size as a function of the difference between means of median perceived tension, and correlation as a function of length of 95% Confidence Intervals, generally confirms the results obtained from ANOVA and paired sample *t*-tests.[329] Calculating and graphing of the ESs and 95%CIs supported the results of data analysis using Analysis of Variance and paired samples *t*-tests. At the same time it brought to light characteristics of the data not evident when only considering the *p*-values given by ANOVA and paired sample *t*-tests. Perhaps most revealing were the 95% Confidence Intervals around Effect Sizes for the effects and interactions considered not significant by ANOVA and/or paired samples *t*-tests ($p > .05$). The graphic representation of Effect Size coupled with 95% Confidence Intervals portrays the likelihood of the occurrence of perceiving no difference between factors or levels rather than dismissing the possibility altogether as tends to occur when $p > .05$ with null hypothesis significance testing.

[329] See Chapter 6 for a complete comparative summary of the results from ANOVA, paired samples *t*-tests, and Effect Sizes with 95% Confidence Intervals.

CHAPTER 5: CONTRIBUTIONS OF MELODIC AND HARMONIC ATTRACTION, PSYCHOACOUSTICS, SPECTRAL ANALYSIS, ROUGHNESS, AND INSTABILITY

Introduction

The purpose of this study was to determine the validity of Lerdahl's tension added values as described in his *Surface Tension Rule*. Furthermore, to modify the tension added values if the empirical evidence did not support Lerdahl's tension added values. Most of the results from the experiment discussed in Chapters 3 and 4 fit well with the tenets of music theory, the predictions of Lerdahl's *Surface Tension Rule*, and our own experiences of Western tonal music. Major Quality chords, in general, are perceived as less tense than are minor Quality chords.[330] Regardless of chord Quality, Root position is perceived as less tense than is First Inversion, which is perceived less tense than Second Inversion. It may have come as a surprise to find Expertise does not affect participants' perception of tension. It is definitely a surprise to find, regardless of Inversion or chord Quality, chords with the root in the Melody (Melody 1) are perceived as embodying more tension then when the third of the chord was in the Melody (Melody 3), or when the fifth of the chord was in the Melody (Melody 5). This result is contrary to the tenets of music theory, to Lerdahl's predictions, and to our own experiences of Western tonal music. Thus, it seems prudent to investigate possible explanations for this curious result before proceeding to a discussion of the various methods used to modify Lerdahl's tension added values.

One answer to this conundrum could be the lack of a musical or tonal context. Participants in this study did not hear the chords in the context of a piece of music, nor did they hear the chords in the context of a harmonic progression. Chords heard within musical and tonal contexts have hierarchical forces acting upon pitch classes, chords, and regions. This study was designed to eliminate the formation of any hierarchies so the ratings could be attributed to the psychoacoustics of the chord formation and not to hierarchies imposed by Western tonality.

Like the precepts of music theory, our experience of chords is also within a musical context. We hear chords within the context of a musical work, which includes, in the case of Western tonal music, tonal hierarchies. Lack of musical context may explain why the principles of music theory, and our experience of listening to and performing Western tonal music, run contrary to the results of this study concerning tension due to Melody.

However, there is a problem assigning lack of a musical or tonal context as an explanation for the results concerning Melody in this study, as Lerdahl's *Surface Tension Rule* pertains to chords out of any musical context. According to Lerdahl, the *Surface Tension Rule* "evaluates the psychoacoustic tension caused by surface features of an event. The sensory dissonance of an event is affected by which pitches are in the bass and which in the soprano, as well as by the presence or absence of sevenths and nonharmonic tones."[331] Other aspects of Lerdahl's model of tonal pitch space—pitch space, sequential tension, hierarchical tension, inherited tension, melodic and harmonic attraction—deal with chords in a musical and tonal context. Lerdahl's *Surface Tension Rule* may be informed by his experience of tonal music, but the rule assesses tension added due to the acoustical properties of a chord, and not its contextual properties. The purpose of this study was to determine validity of the tension added values Lerdahl

[330] Throughout this paper, factors (Inversion, Melody, and chord Quality) and their levels (Root, First, Second, Melody 1, Melody 3, Melody 5, and Major) are capitalised for ease of identification. The exception is minor chord Quality, which begins with a lower case letter, in keeping with Weber's labelling system (upper case for Major chords and regions, lower case for minor chords and regions).
[331] Lerdahl (2001), 150.

assigns for Inversion and Melody in his *Surface Tension Rule*. What follows is a discussion of some features of, and acoustical properties of, the stimuli used in this study. This examination is important, as consideration of the psychoacoustic characteristics of the stimuli used is valuable in view of Lerdahl's explanation of surface tension, and the results of this study.

Disruptor Sequences

If lack of musical context is necessary to evaluate "the psychoacoustic tension caused by surface features of an event,"[332] perhaps the design of the study did not eliminate a musical context. Perhaps, despite the intervention of Disruptor Sequences, participants were able to relate each chord to the tonal context of the previous chord. However, even if this were the case, the design of the experiment controls for order effect by randomising the order in which each participant heard the chords. No one participant heard chords in the same order as any other participant. Thus, ineffectiveness of Disruptor Sequences to disrupt tonal hierarchy is an unlikely answer.

If the results were not due to relating successive chords one to another, maybe participants were relating the chords to their associated Disruptor Sequences. Recall, Disruptor Sequences were played before each target chord. Disruptor Sequences varied in length from .875s to 1.5s. Thus, let us first consider length of Disruptor Sequences as a confounding variable in this study. Table 5.1 shows the mean of medians tension perceived for each chord formation, and the length of their associated Disruptor Sequence (in seconds).[333]

The longest Disruptor Sequence lasts 1.5s. The chord formations associated with a Disruptor Sequence of this length are R1M, R1n, S5M, and S5n. Of the four chord formations associated with 1.5s Disruptor Sequences, R1M and R1n record the highest mean of medians perceived tension values within their respective Inversion categories (Root position), and the lowest within their respective Melody 1 categories. Yet, S5M and S5n have the lowest mean of medians perceived tension values within their respective Inversion categories.[334] The Disruptor Sequence lasting 1.125s is associated with R3M, F5n, S1M, and S1n. R3M and F5n have the lowest perceived tension values in their respective Inversion_Quality categories while S1M and S1n have the highest perceived tension values in their respective Inversion_Quality categories.

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[332] Lerdahl (2001), 150.

[333] Because the data were skewed, the median rather than the mean was chosen to measure the central tendency of the data. Skewness was not eliminated with removal of outliers or with various types of data transformation. See Appendices A and B for more detail.

[334] Mean of median tension perceived for S5M is between that perceived for F5M and R5M. Mean of median tension perceived for S5n is highest for Melody 5_minor.

Table 5.1.

Chord formation, mean of medians tension, and length of disruptor sequence

Chord	Mean	Disruptor (s)	Chord	Mean	Disruptor (s)
R1M	24.20	1.5	R1n	56.53	1.5
R3M	20.15	1.125	R3n	48.49	1.0
R5M	22.61	1.25	R5n	49.98	1.25
F1M	36.03	1.25	F1n	57.19	1.375
F3M	28.71	.875	F3n	53.28	1.375
F5M	25.30	1.0	F5n	52.79	1.125
S1M	34.76	1.125	S1n	60.90	1.125
S3M	28.25	1.375	S3n	59.01	1.25
S5M	23.62	1.5	S5n	57.02	1.5

Note. Chord formations are reported by Inversion_Melody_chord Quality where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor. Mean = mean of medians perceived tension. The length of Disruptor Sequences is in seconds.

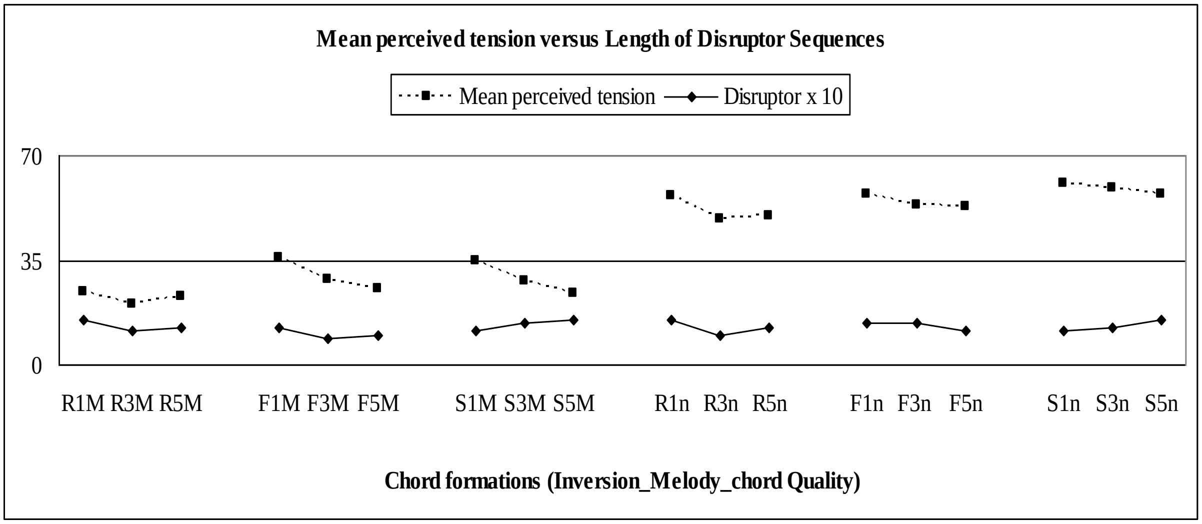

Figure 5.1. Chord formations are recorded by Inversion_Melody_chord Quality where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor. The length of Disruptor Sequences is actual length (in seconds) times 10. Mean values are mean of medians perceived tension.

We see in Figure 5.1, the relative lengths of the Disruptor Sequences and the mean of the medians perceived tension appear to mirror each other quite well for Root position Major, and somewhat for Root position minor and First Inversion Major. This relationship does not hold true for First Inversion minor, Second Inversion Major, and Second Inversion minor. From the data in Table 5.1 and the graph in Figure 5.1, we can conclude, regardless of Inversion, Melody, and/or chord Quality, the length of the Disruptor Sequence does not appear to influence perceived tension. This conclusion is supported by Pearson's correlation coefficient, $r(16) = .15$, $p = .55$, which suggests it is reasonable to conclude no relationship exists between the length of the Disruptor Sequence and the mean of medians perceived tension.

Melodic Attraction[335]

Weber, Schenker, and Lerdahl believe current musical events affect our understanding of past musical events. Lerdahl's model of hierarchical tension is based on this assertion.[336] In this study, the Disruptor Sequences were intended literally to disrupt participants' ability to assign a tonal hierarchy between successive chords. The Disruptor Sequences did not contain any of the notes found in their associated target chords. Disruptor Sequences were pentatonic and not based on Major or minor diatonic scales. All Disruptor Sequences were ascending. Lower and upper notes of the Disruptor Sequences were either a semitone or tone from the lower and upper chord tones of the target chord.

Perhaps the 2s interval between the presentation of the Disruptor Sequence and its associated target chord was not long enough to forbid the forming of a hierarchical relationship between the two. We can determine if a hierarchical relationship existed between the outer pitches of the Disruptor Sequences and the outer pitches of the target chords. To do this, we turn to Lerdahl's theory of Melodic Attraction.

Calculation of the attraction between 2 melody notes requires the use of a modified version of Lerdahl's Diatonic space. His Diatonic space has 5 levels of stability. Stability is inversely related to tension. The most stable level is the Root, followed by the Fifth, Triadic, Diatonic, and Chromatic.[337] Lerdahl removes the level of the Fifth for calculating Melodic Attraction. Each level is assigned an anchoring strength (directly related to stability and inversely related to depth of embedding of a pitch).

Level	Anchoring Strength												
Root	4	0											
Triad	3	0				4			7				
Diatonic	2	0		2		4	5		7		9		11
Chromatic	1	0	1	2	3	4	5	6	7	8	9	10	11

Figure 5.2. Attraction Pitch space for I/**C** (using pitch classes, where 0 = C, 1 = $C^{\#}/D^{b}$, et cetera) indicating level and Anchoring Strength.

We know listeners assign the first chord heard, the hierarchical placement of tonic. It is not implausible to suggest participants heard each chord stimulus as a temporary tonic.[338] At the very least, it is fair to suggest participants heard the target chord as belonging to a region in which all chord notes were part of that region. If these assumptions are accepted, Melodic Attraction between pitches of the Disruptor Sequence and its target chord can be calculated.

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335 An explanation of Lerdahl's concept of melodic attraction and its corresponding formula is found in Chapter 1.
336 For a full discussion of hierarchical tension see Chapter 1.
337 Diatonic space is explained in more detail Chapters 1 and 2.
338 See Chapter 1, "Finding the tonic" where Lerdahl says, "when a single note or chord sounds in isolation, the listener assumes that is it the tonic, for the shortest distance is from an event to itself." Lerdahl (2001), 194.

Let us first consider the possibility of the influence of Melodic Attraction between the upper note of the Disruptor Sequence and the upper note of the target chord. Using the region of C as an example, let us consider Root position Major chords first. In this study, Melody 1 (C_5) was preceded by $C^{\#}_5$ of the Disruptor Sequence, Melody 3 (E_4) was preceded by $F^{\#}_4$, and Melody 5 (G_4) was preceded by $G^{\#}_4$. Melody 1 and Melody 5 were separated from the pitch of their associated Disruptor Sequence by a tone, Melody 3 by a semitone. To calculate Melodic Attraction, the depth of embedding of the second pitch is divided by the depth of embedding of the first pitch. This is multiplied by 1 divided by the square of the semitone distance between the two tones.

The attraction between Melody 1 and its associated tone from the Disruptor Sequence is 4; for Melody 3 and its associated tone, .75; for Melody 5 and its associated tone, 3.[339] This is looking promising as, like the perceived tension values, Melody 1 has a higher number than Melody 3 or Melody 5; that is, Melody 1 has a higher Melodic Attraction value than either Melody 3 or Melody 5. However, Melodic Attraction is inversely related to tension. Thus, Lerdahl predicts the tension as $C^{\#}$ moves a semitone to C is 1/4 or .25, 1.33 as $F^{\#}$ moves a tone to E, and .33 as G # moves a semitone to G.

Figure 5.3 shows the mean of medians perceived tension for each chord formation, and tension due to Melodic Attraction.[340] There appears to be no consistent relationship between perceived tension and the tension due to Melodic Attraction between the last note of the Disruptor Sequence and the top note of the chords presented to participants. This conclusion is supported by Pearson's correlation coefficient, $r(16) = -.086$, $p = .73$, which suggests Melodic Attraction between the top note of the Disruptor Sequence and the top note of the target chord did not affect perceived tension.

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[339] For Melody 1: (Depth of embedding of C/Depth of embedding of C#) x (1/square of semitone distance) = (4/1) x (1/1) = 4; for Melody 3: (3/1) x (1/4) = 3/4 = .75; for Melody 5: (3/1) x (1/1) = 3.

[340] For graphing purposes, the value of tension due to Melodic Attraction is multiplied by 10 to be near the range of perceived tension values.

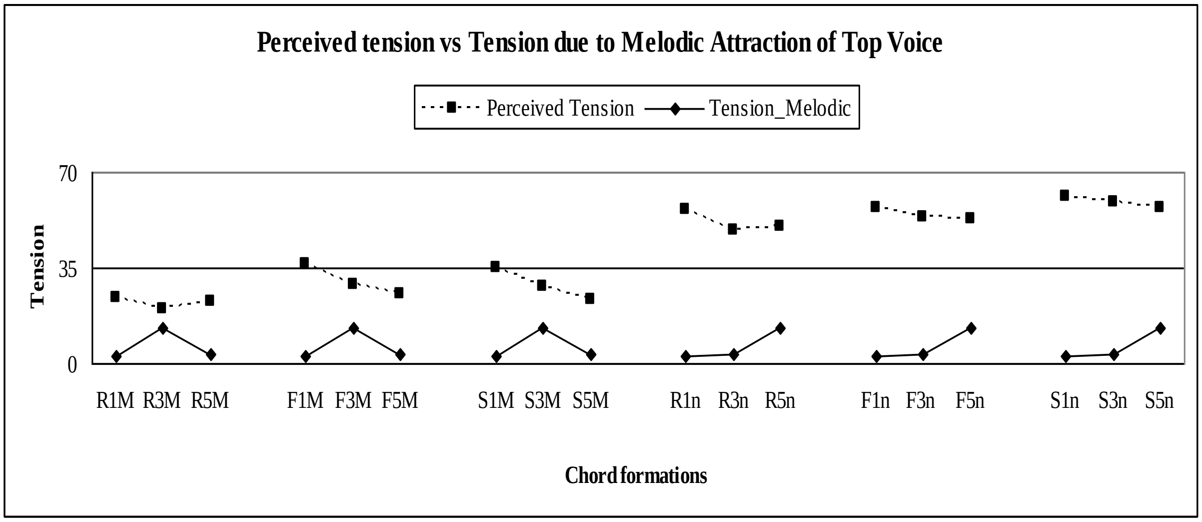

Figure 5.3. Mean of medians perceived tension versus Melodic tension due to attraction between last note of Disruptor Sequence and top chord note. Melodic tension values are multiplied by 10 so to fit closer to the range of perceived tension values. Note: Chord formations are recorded by Inversion_Melody_chord Quality where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor.

Harmonic Attraction[341]

Lerdahl's *Surface Dissonance Rule* is concerned with pitches in the top voice (identified as Melody in this study), and in the bottom voice (identified as Inversion in this study). Lerdahl elaborates on his concept of Melodic Attraction to include all chord notes. He calls this Harmonic Attraction, and sums the Melodic Attraction values for all chord voices. There is no one-to-one relationship between the 7-12 pitches of the Disruptor Sequences and the 4 pitches of the target chords. It is possible, however, to consider the Melodic Attraction between the most salient pitches— the lowest note of the Disruptor Sequence and the lowest note of the target chord, along with the highest note of the Disruptor Sequence and the highest note of the target chord.[342] The sum of the two attraction forces, then, can be compared to the levels of perceived tension.

The Melodic Attraction formula for the lowest notes is the same as shown above for the highest notes. For example, the bass C_3 of the C Major Root position chord is preceded by $B^b{}_2$, the lowest note of the associated Disruptor Sequence. This results in a Melodic Attraction value of 1.[343] Table 5.2 shows the calculated Melodic Attraction between the highest pitch of the Disruptor Sequence and the highest pitch in the target chord (S_Attraction), and the Melodic attraction between the lowest pitch of the Disruptor Sequence and the lowest pitch of the target chord (B_Attraction). Following Lerdahl's *Harmonic Attraction Rule*, the total attraction is the sum of

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[341] An explanation of Lerdahl's concept of melodic attraction and its corresponding formula, see Chapter 1.
[342] Recall, Lerdahl's *Surface Tension Rule* pertains to the affect of pitches in the bass (Inversion) and in the soprano (Melody).
[343] For Root position Major chords: (Depth of embedding of C/Depth of embedding of Bb) x (1/square of semitone distance) = (4/1) x (1/4) = 1; Root position minor chords: (Depth of embedding of C/Depth of embedding of B) x (1/square of semitone distance) (4/1) x (1/1) = 4.

S_Attraction and B_Attraction. The predicted tension value is the inverse of the Total Attraction. These values are plotted on the graph at Figure 5.4.

Table 5.2.

Harmonic Attraction between Disruptor Sequences and Target chords

Chord	Mean	S_Attraction	B_Attraction	Total	Tension
R1M	24.2	4	1	5	0.20
R3M	20.15	0.75	1	1.75	0.57
R5M	22.61	3	1	4	0.25
F1M	36.03	4	3	7	0.14
F3M	28.71	0.75	3	3.75	0.27
F5M	25.3	3	3	6	0.17
S1M	34.76	4	3	7	0.14
S3M	28.25	0.75	3	3.75	0.27
S5M	23.62	3	3	6	0.17
R1n	56.53	4	4	8	0.13
R3n	48.49	3	4	7	0.14
R5n	49.98	0.75	4	4.75	0.21
F1n	57.19	4	0.75	4.75	0.21
F3n	53.28	3	0.75	3.75	0.27
F5n	52.79	0.75	0.75	1.5	0.67
S1n	60.9	4	3	7	0.14
S3n	59.01	3	3	6	0.17
S5n	57.02	0.75	3	3.75	0.27

Note. Chord formations are recorded by Inversion_Melody_chord Quality where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor. Mean = mean of medians perceived tension. S_Attraction = the Melodic attraction between the highest note of the Disruptor Sequence and the highest note of the target chord; B_Attraction = the Melodic attraction between the lowest note of the Disruptor Sequence and the lowest note of the target chord. (Harmonic) Tension = 1/Total Attraction.

We can see, from the data in Table 5.2 and the graph in Figure 5.4, the Melodic Attraction between the bottom and top notes of the Disruptor Sequences and the bottom and top notes of the target chord does not appear to influence participants' perception of tension embodied in the target chords. The results of this study indicate, regardless of Inversion or chord Quality, Melody 1 was perceived as embodying the most tension. Application of Lerdahl's *Harmonic Attraction Rule* results in the highest attraction/lowest tension values for Melody 1. Thus, the unexpected results for Melody 1 are not a consequence of the interaction of the attractional forces between the lowest and highest pitches of the Disruptor Sequence and those of its target chord. This conclusion is supported by Pearson's correlation coefficient, $r(16) = -.11$, $p = .66$, which suggests it is unlikely there is a relationship between the mean of medians perceived tension and Harmonic Attraction between the outer pitches of the Disruptor Sequences and their related target chords.

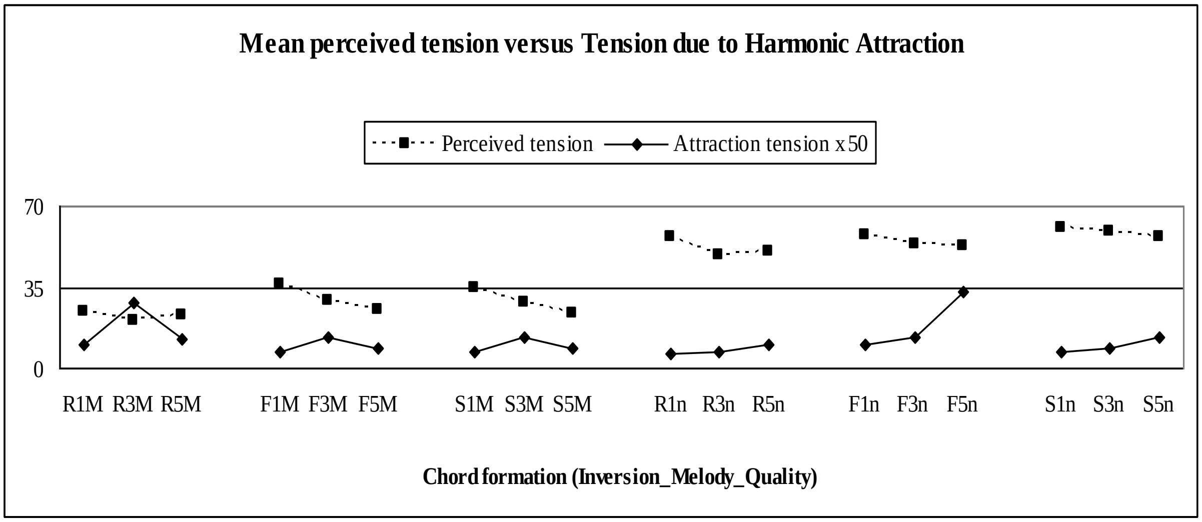

Figure 5.4. Mean of medians perceived tension compared with tension due to Harmonic Attraction between lowest and highest pitches of Disruptor Sequences and lowest and highest pitches of target chords. Melodic tension values are multiplied by 50 so to fit closer to the range of perceived tension values. Chord formations are recorded by Inversion_Melody_chord Quality, where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor.

Psychoacoustics

Terhardt and Parncutt are two familiar names in the field of psychoacoustics. Terhardt determined the roots of Major triads, regardless of Inversion, were unambiguous. The roots of minor triads, regardless of Inversion, were more ambiguous. Terhardt recorded Major and minor triads and Inversions played on a piano (the roots of which were A_4). Using his algorithm, he identified the seven most prominent pitches and their weighting. He found, regardless of Inversion, the pitch class of the root of the Major triads was very pronounced. The same was not true for minor triads and Inversions. "Besides the fundamental note A [in minor triads], there occur also the notes D, C, and F, thus reflecting the harmonic flexibility and ambiguity of minor triads which is known from actual music."[344]

Parncutt attempted to revise Terhardt's model as it was unable to predict the root of minor triads. Terhardt's model was based on the presence of, in the harmonics of the sound event, pitch classes equivalent to the root, serving to reinforce that pitch class as root. Parncutt's revision to Terhardt's model assigns weighting to subharmonic pitch classes. In doing so he arrives at what he calls "root-supporters." These are intervals, above the root and occurring in the correct order, disambiguate the identification of the chord root by listeners.[345] Root-supporters aid in promoting

[344] Ernst Terhardt, Gerhard Stoll, and Manfred Seewann, "Pitch of complex signals according to virtual-pitch theory: Tests, examples, and predications," *Journal of the Acoustical Society of America*, 71, no. 3 (1982), 677.
[345] In the case of Major and minor chords, intervals of Perfect 4, minor 6, and Major 6 above the root should be below Perfect 1 (8), Perfect 5, Major 3, and minor 3. Furthermore, if a minor 3 above the root is the highest pitch it should be supported by a Perfect 1 (8), Perfect 5, or Major 3. All chord formations in the present study follow these ruling.

the salience of the chord root. Parncutt goes further and identifies the effects of Inversion,[346] spacing between chord voices,[347] and chord doubling.[348]

Auditory Roughness

Vassilakis and Fitz's Spectral and Roughness Analysis (SRA)[349]

Characterisation of musical dissonance is influenced by context, history, and culture. For Pythagoreans, dissonant intervals were those whose ratios used numbers larger than 4.Thus, the Major third (5:4) was considered a dissonance and the Perfect fourth (4:3) a consonance. By the 14th century, the harmonic Major third was considered a consonance, and the harmonic Perfect fourth a dissonance. A Major seventh added to a tonic chord could be considered dissonant when heard out of context. However, the sense of dissonance is mitigated when heard in the context of a sequence of seventh chords.

Auditory roughness, on the other hand, is a physiological response to the properties and interactions of the sound waves.[350] High auditory roughness values are thought to correlate with musical dissonance/instability/tension. As Lerdahl's *Surface Tension Rule* is concerned with the psychoacoustical properties of chords, considering the auditory roughness of the stimuli used in this study may help explain the results.

The stimuli from this study were analysed using an algorithm developed by Vassilakis and Fitz. [351] Vassilakis found, "[f]or musicians within the Western musical tradition, roughness ratings of harmonic intervals agree with the roughness degrees estimated using the proposed roughness estimation model and correlate with the dissonance degrees suggested by Western music theory."[352] Music theory, and Lerdahl's *Surface Tension Rule*,

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[346] "The bass note of an ordinary, 'monotonal' chord is always a root support; it cannot be a detractor, as this would change the root. So the bass note of an inverted chord must lie at an interval of P5, M3, m7, m3, or M2 above the 'missing root' in the bass." Richard Parncutt, "Revision of Terhardt's Psychoacoustical Model of the Root(s) of a Musical Chord, *Music Perception*, Vol. 6, no. 1 (1988), 88. (P = Perfect, M = Major, m = minor) Following these guidelines, all Inversions of chords used in the present study would support the roots of the chord.

[347] The greater the distance between the bass note and the other notes of the chord, the more likely it is for the bass note to be heard as the chord root. In the present study, the distance between bass and tenor for R1 and R3 was P5, and P8 for R5. The difference in the perceived tension ratings for R1 and R3 is not explained by chord spacing. The distance between bass and tenor for F1 was m6/M6 and m3/M3 for both F3 and F5. (The first interval is for Major chord formations/the second interval is for minor chord formations.) Again chord distance does not explain perceived tension ratings. Finally the distance between bass and tenor for S1 and S5 is M6/m6 and P8 for S3. This does not correlate with perceived tension in this study.

[348] "The chances of a note being heard as a root are increased if that note is *doubled* ... for example, the third of the major triad ... can noticeably increase root ambiguity." Parncutt (1988), 89. This was not the case in the present study as the third was doubled in F3 yet perceived tension was lower than that of F1 in which the root was doubled.

[349] Vassilakis's algorithm is found in Pantelis Vassilakis, "Auditory Roughness as a Means of Musical Expression," *Selected Reports in Ethnomusicology Perspectives in Systematic Musicology* 12 (2005): 141.

[350] Auditory roughness is a result of the interaction of the fluctuation of amplitudes of the waveforms (due to constructive and destructive interference), and the critical bandwidth of the ear's basilar membrane. Up to a point, as the rate of amplitude fluctuation increases so does the perception of roughness. The perception of roughness gradually weakens after the maximum amplitude fluctuation is reached. If two frequencies are within the same critical bandwidth on the basilar membrane, roughness is perceived. Two separate tones are perceived if the frequencies of the pitches occur within different regions of the basilar membrane.

[351] Pantelis Vassilakis and Kelly Fitz,"*SRA*: A Web-based Research Tool for Spectral and Roughness Analysis of Sound Signals," accessed August 26, 2015, http://musicalgorithms.ewu.edu/algorithms/roughness.html or http://www.acousticslab.org/roughness.

[352] Pantelis Vassilakis, "Auditory Roughness as a Means of Musical Expression," *Selected Reports in Ethnomusicology Perspectives in Systematic Musicology* 12 (2005): 131.

predict Root position will be less tense than First Inversion, which will be less tense than Second Inversion; Major Quality chords will be less tense than minor Quality chords; chords with the third (Melody 3) in the Melody will be more tense than those with the fifth (Melody 5) in the Melody, which are more tense than chords with the Root (Melody 1) in the Melody.

The results of this study support two of three predictions—Inversion and chord Quality—but not Melody. Chords with the Root (Melody 1) in the Melody were judged as most tense. In an attempt to discern a possible explanation for this unexpected result, each of the 216 chord stimuli used in this study were analysed by *SRA*. Values of auditory roughness were obtained for each chord at 250ms intervals.[353] This resulted in 15-18 roughness values for each chord formation, from which a median value of roughness, for each of the nine Major and nine minor chord formations, was calculated (Table 5.3).[354, 355]

Table 5.3.

Median roughness and mean of medians perceived tension values for chord formations by chord Quality

Chord formation	Major Roughness	Major Tension	minor Roughness	minor Tension
R1	37.88	24.19	42.86	56.53
R3	62.67	20.15	69.56	48.49
R5	60.73	22.61	65.92	49.98
F1	38.57	36.03	45.83	57.19
F3	71.34	28.71	81.43	53.28
F5	57.74	25.3	59.23	52.79
S1	61.37	34.76	62.25	60.9
S3	51.22	28.25	62.41	59
S5	45.58	23.62	44.06	57.02

Note. Median roughness and mean of medians perceived tension for Major and minor chord Qualities where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

Similar to the ratings for mean of medians perceived tension, *SRA* found Major Quality chords to be less rough than minor Quality chords. We can see in Figure 5.5, as with perceived tension, median roughness values for Major and minor Quality chord formations follow the same basic course, $r(7) = .95$, $p < .001$. However, as Figure 5.5

[353] See Appendix H for an example of data collected for each of 216 target chords.
[354] The target chords sounded for 4s. Roughness, based on the interactions of 50 partials at each time point, was calculated every 250ms, beginning at 250ms and ending at 4000-4500ms. Vassilakis cautions the reported time point may differ slightly from the specified time point. Thus, roughness calculations were performed after 4000ms in some cases or not exactly at 250ms intervals.
[355] I chose to report median roughness as Vassilakis calculated median roughness from 5 roughness values measured within 100ms window of each time point. See Appendix H for an explanation of Vassilakis' method.

shows, median roughness as calculated by *SRA* is not generally a good predictor of mean of medians perceived tension for the stimuli used in this study, $r(16) = .12$, $p = .63$.[356]

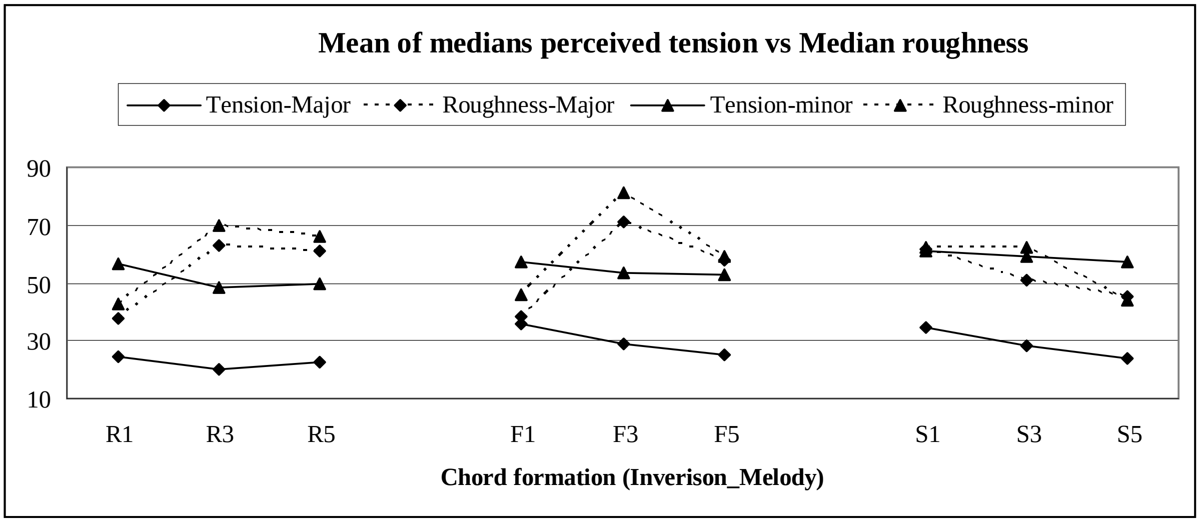

Figure 5.5. Median roughness versus mean of medians perceived tension where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor.

While Figure 5.5 demonstrates, in general, median roughness, as calculated by *SRA*, does not predict mean of medians perceived tension, it appears median roughness and mean of medians perceived tension correlate well for Second Inversion Major Quality chords, but not for other Major Quality or any minor Quality chords. A low roughness value often results in a high rating of perceived tension and vice versa. This observation is confirmed by the negative sign before the numerical values of the correlation coefficients for mean of medians tension perceived and median roughness—minor Quality chords, $r\ (9) = -.45$, $p = .22$, and for Major Quality chords, $r\ (9) = -.15$, $p = .69$. Thus, as mean of medians perceived tension increased, roughness decreased—the opposite of what is expected. The presence of $p > .05$ indicates there is insufficient evidence to suggest level of roughness can predict perceived tension.

SRA and chord Quality

Figure 5.6 shows both mean of medians perceived tension and median roughness are higher for minor Quality chords than for Major Quality chords. In this regard, *SRA* is effective in predicting perceived tension. The difference between mean of medians perceived tension for Major and minor Quality chords (27.95) is larger than the difference in their roughness values (5.16). The steeper slope of the mean of medians perceived tension line, in comparison to the median roughness line, indicates chord Quality has more effect upon perceived tension values than it does upon roughness values.

[356] Most of the correlation coefficients used to determine the existence and strength of the relationship between perceived tension and roughness have *p*-values greater than .05. This suggests no linear relationship exists between the variables. That is, there is insufficient evidence to suggest level of roughness can predict perceived tension.

SRA and Inversion

Figure 5.7 shows increase in mean of median perceived tension between Root position and First Inversion is greater than the increase in median roughness for the same chord Inversions. Mean of median perceived tension continues to increase for Second Inversion while median roughness decreases. Thus, roughness, as determined by *SRA*, does not predict perceived tension due to Inversion. Disregarding the *p*-value for the moment, and looking only at the correlation coefficients, we find median roughness correlates most strongly with the mean of medians for Second Inversion, $r\ (4) = .39$, $p = .33$. Roughness calculated by *SRA* is much less successful at predicting perceived tension in First Inversion, $r(4) = -.03$, $p = .95$, and Root position, $r(4) = .16$, $p = .72$. The *p*-values, however, indicate it is unlikely roughness can predict participants' perception of tension due to Inversion in stimuli used in this study.[357]

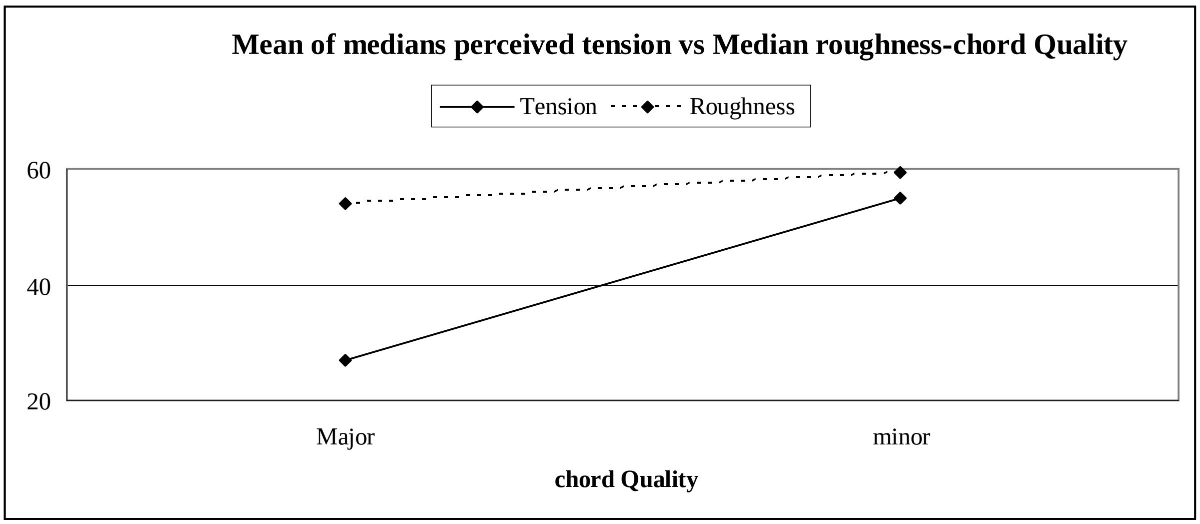

Figure 5.6. Median roughness versus mean of medians perceived tension by chord Quality.

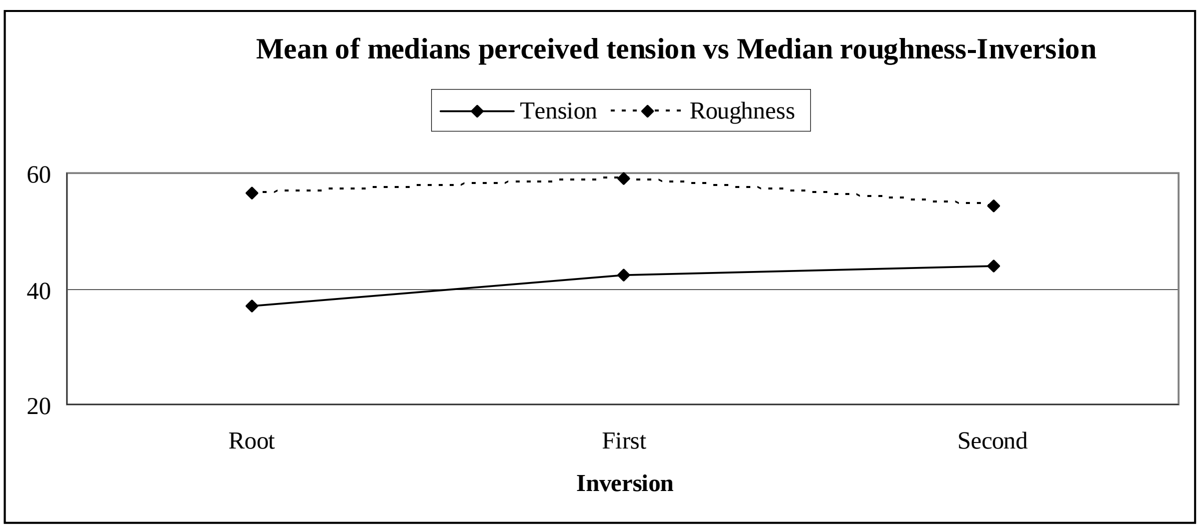

Figure 5.7. Mean of medians perceived tension and median roughness for Inversion.

[357] $p > .05$ indicates it is unlikely a relationship exists between perceived tension due to Inversion and auditory roughness.

SRA and Melody

Spectral and Roughness Analysis was unsuccessful in predicting listeners' perception of tension for chord Quality and for Inversion. Can it explain the unexpected result of Melody 1 rated as tenser than either Melody 3 or Melody 5? The graph at Figure 5.8 suggests *SRA* cannot explain why participants—contrary to tenets of music theory, our own experience of tonal music, and to Lerdahl's *Surface Tension Rule*— rated Melody 1 as most tense, regardless of Inversion and/or chord Quality. Figure 5.8 shows Melody 1 as least rough, but most tense. Melody 3 is shown to possess the highest amount of roughness but lower perceived tension. The correlation coefficient suggests roughness, as determined by *SRA*, weakly correlates with perceived tension due to Melody, $r(16) = .14$, $p = .56$. Once again, the *p*-value suggests it is unlikely roughness can predict perceived tension perceived due to Melody.

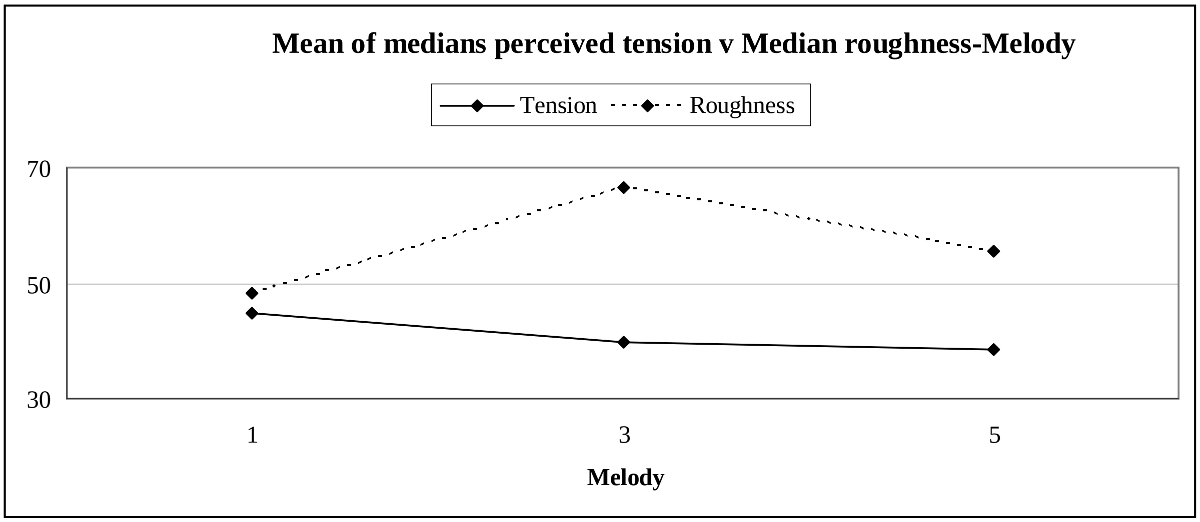

Figure 5.8. Mean roughness and mean of medians perceived tension for Melody, where 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

SRA Conclusions

Roughness is thought to be an important component of our perception of musical dissonance. Lerdahl, in *Tonal Pitch Space*, links surface dissonance to tension.[358] *Spectral and Roughness Analysis* reveals listeners, presented with chords outside of a musical and tonal context, experience more roughness when hearing minor Quality chords than when hearing Major Quality chords. This aligns with the ratings of tension perceived by participants in this study. The spectral analysis and the resulting levels of roughness of the four-note chords used in this study, do not predict tension due to Inversion or Melody. Therefore, participants' higher tension rating for Melody 1 chords in this study cannot be explained by Vassilakis and Fitz's *Spectral and Roughness Analysis*.

Vassilakis tested *SRA* by having 2 groups of musicians familiar with Western tonal music rate either the roughness or the dissonance upon hearing intervals.[359] Based on his experiment he concludes, "[t]he results,

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[358] Recall, Lerdahl's *Surface Tension Rule* adds tension due to sensory dissonance of a musical event, which is affected by the pitches in the bass (Inversion) and the soprano (Melody). Lerdahl (2001), 150.

[359] Using equal temperament, Vassilakis had participants rate all intervals, above C_4, found between C_4 and C_5. In this study, pitches ranged from F_2 to G_5. Vassilakis' stimuli were intervals composed of two notes. Analysing the stimuli in this study was more complicated as they were more complex because they were composed of four-note chords.

therefore, indicate that roughness constitutes a significant but [*sic*] not the sole factor guiding listeners in their dissonance judgments."[360] This present study supports his conclusion. In some instances, for example Second Inversion Major chords, auditory roughness appears linked to participants' perception of tension. In other instances, other factors seem to affect participants' perception of tension embodied in Major and minor chords, with three possible Inversions and three possible Melody notes, heard outside a musical and tonal context.

Cook Seeing Harmony (SH)

Vassilakis' experiment is different from the present study in an important way. He asked participants in his study to rate roughness and dissonance of intervals or dyads. The present study required participants to rate tension embodied in four-note chords or tetrads. Norman Cook, believing perception of what Lerdahl calls tension is due to more than the sum of the interactions of tones and partials, created a programme, *Seeing Harmony* (*SH*), which is capable of analysing chords containing up to 6 tones.[361] He calculates Dissonance (the intervallic contribution) by summing dissonance of pairs of intervals and their partials. He calculates Tension (the chordal contribution) which is due to the relative size of successive intervals, including partials, in each chord. Instability is determined by summing Dissonance and Tension.[362]

Both Vassilakis and Cook consider the interaction of amplitude, and chord tones and their partials. Vassilakis' *SRA* measured 50 frequency peaks, ordered by amplitude, of the actual sound stimuli used in this study. The results from Cook's *SH* are not from analysing the actual sound stimuli used in this study. Rather, they are obtained from the interaction of tones and partials entered into the program by frequency (Hz) or tone number (where Tone 1 = C_4, middle C).

Table 5.4 reports the values obtained from *SH* for the 18 different chord formations used in this study.[363] Dissonance from the interaction of the intervals present in the chords is higher for Major Quality chords than for their minor counterparts. The exceptions are First Inversion_Melody 3 (F3) Second Inversion_Melody 1 (S1) and Second Inversion_Melody 5 (S5) where Major Quality chords have less Dissonance than minor Quality chords (F3 and S1) or equal Dissonance (S5). Dissonance, regardless of chord Quality, is higher for Melody 1 than for Melody 3 and Melody 5 for Root and First Inversion. The Dissonance value for Melody 5, regardless of chord Quality, is highest for Second Inversion.

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360 Vassilakis (2001), 136.
361 See Appendix I for details regarding the implementation of Cook's program for the stimuli in this study.
362 For a more complete explanation and the equations used, see Appendix I.
363 3 Inversions (Root, First, Second) x 3 Melody notes (Root of chord, third of chord, fifth of chord) x 2 chord Quality (Major, minor) = 18 different chord formations. The stimuli totalled 216 (18 chord formations x 12 regions or keys = 216).

Table 5.4.

Cook's Dissonance, Tension, and Instability, with mean of medians Perceived Tension, by chord Quality

	Major				minor			
	D	T(C)	I	T(P)	D	T(C)	I	T(P)
R1	12.07	6.06	13.31	24.2	12.06	6.07	13.32	56.53
R3	7.12	6.44	8.45	20.15	6.77	6.46	8.11	48.49
R5	8.94	6.3	10.24	22.61	8.68	6.32	9.99	49.98
F1	10.13	6.23	8.99	36.03	9.03	6.3	10.34	57.19
F3	4.89	6.57	6.57	28.71	4.92	6.57	6.28	53.28
F5	6.11	6.49	7.46	25.3	5.74	6.92	7.71	52.79
S1	6.42	6.48	7.76	34.76	6.59	6.47	7.93	34.76
S3	10.42	6.2	11.71	28.25	9.92	6.23	11.21	28.25
S5	12.07	6.1	13.33	23.62	12.07	6.07	13.33	23.62

Note. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; D = Dissonance, T(C) = Tension from Cook's program, I = Instability, and T(P) = mean of medians perceived tension from this study.

Dissonance alone, with higher values for Major Quality chords than for minor Quality chords runs contrary to music theory tenets, music perception predictions, and results of perceived tension from this study. The high Dissonance value for Melody 1 (Root and First Inversion) seems promising as an explanation of the results of this study. Unfortunately, *SH* Dissonance for Second Inversion_Melody 1 is lower than that for the same Inversion with Melody 3 and Melody 5.

Cook's Tension values are narrow in range (6.06 to 6.92) in comparison to Dissonance and Instability. There is no consistent relationship between chord Quality and level of Tension. In some instances, there is more tension in Major Quality chords than in minor Quality chords (F1 and F5). At other times the reverse is true (S1 and S5). At still other times the Tension for chord Quality is equal (F3) or near equal (R1 and S1). Nor is there consistency with respect to Melody. Melody 3 is most tense for Root and First Inversion Major Quality chords, but only First Inversion minor Quality chords. Melody 1 has lowest Tension for Root and First Inversion chords regardless of chord Quality. This inconsistency makes Cook's Tension ineffective for predicting tension perceived in four-note chords heard out of musical and tonal context.

It is, however, *SH*'s value for Instability, incorporating Dissonance (interval effects) and Tension (chordal effects), which is of interest. As Figures 5.9 and 5.10 show, Instability appears to be useful for predicting perceived tension in Root position Major and minor Quality chords, and in First Inversion minor Quality chords. In these instances, high Instability occurs with high perceived tension, and low Instability occurs with low perceived tension. This apparent relationship follows Lerdahl's theory and our own experience of Western tonal music. Instability appears somewhat useful in predicting perceived tension in First Inversion Major Quality chords. The reverse is true with Second Inversion chords as, regardless of chord Quality, high Instability occurs with low perceived tension and vice versa. This relationship is contrary to Lerdahl's theory and our experience of Western tonal music.

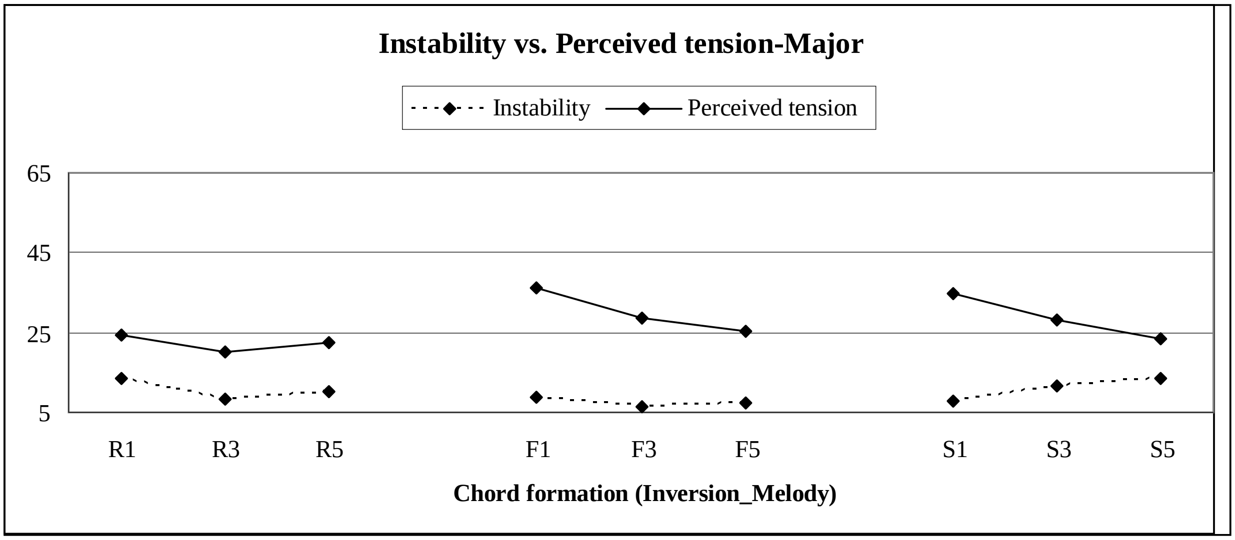

Figure 5.9. Cook's value of Instability compared with mean of medians perceived tension of Major Quality chord formations, where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice. Data is from Table 5.2.

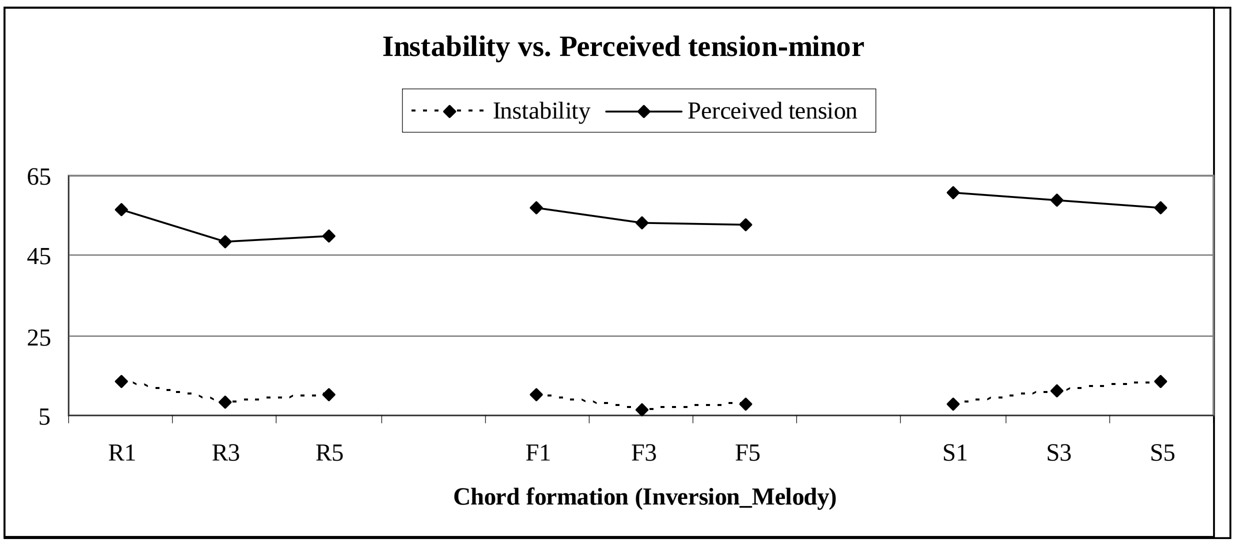

Figure 5.10. Cook's value of Instability compared with mean of medians perceived tension of minor Quality chord formations, where Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice. Data is from Table 5.2.

SH and chord Quality

Results from this study demonstrated the role of chord Quality in participants' perception of tension, as Major Quality chords were rated as less tense than were minor Quality chords. Figure 5.11 suggests Instability cannot predict perceived tension due to chord Quality.

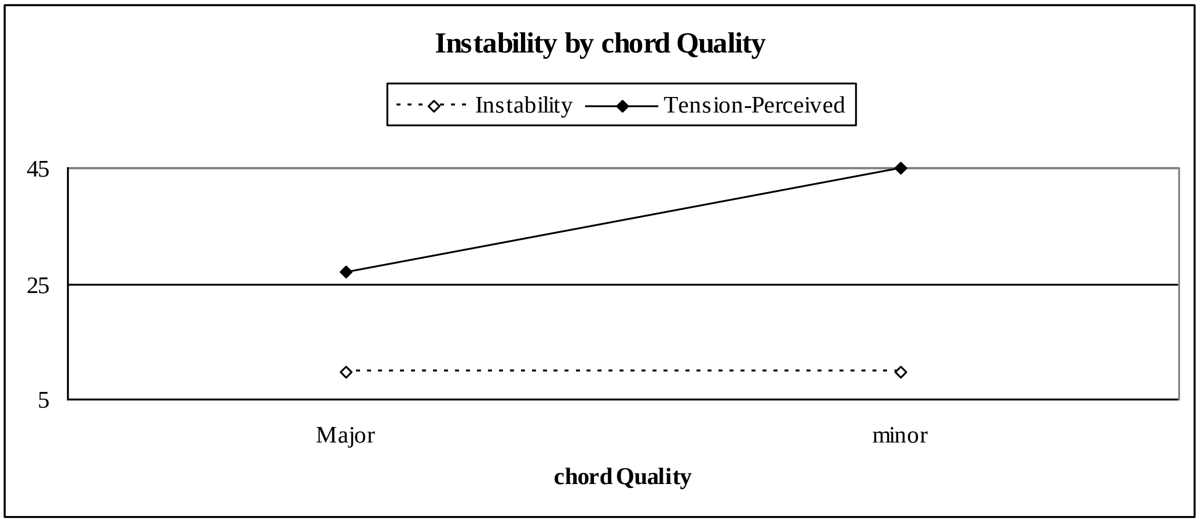

Figure 5.11. Mean Instability values and mean of medians perceived tension for all Major Quality and minor Quality chord formations. See Appendix I Table I.3 for data.

Figure 5.12 shows, running contrary to tenets of music theory and to the results of this study, Root position Major Quality chords appear to have slightly higher Instability values than do minor Quality chords in Root position. The opposite occurs with First and Second Inversion chords. Instability is higher for Melody 1 and Melody 5 in minor Quality First and Second Inversion chords than for the same Inversions of Major Quality chords. Instability is lower for Melody 3 in minor Quality First and Second Inversion chords than for Major Quality chords in these same positions.

The greatest difference in Instability values due to chord Quality occurs for First Inversion Melody 1 chord formations. Otherwise, there appears to be little difference between the Instability values for parallel Major and minor Quality chord formations. A paired samples *t*-test confirms this observation, $t(8) = .24$, $p = .81$. The *p*-value is greater than .05 suggesting there is no difference between the Instability values for Major and minor Quality parallel chord formations. For example, the Instability value for First Inversion Major Quality chords with Melody 5 is not significantly different from that of First Inversion minor Quality chords with Melody5.[364]

[364] Cook believes, in comparison to other triads (augmented, diminished, suspended fourth), Major and minor triads are stable.

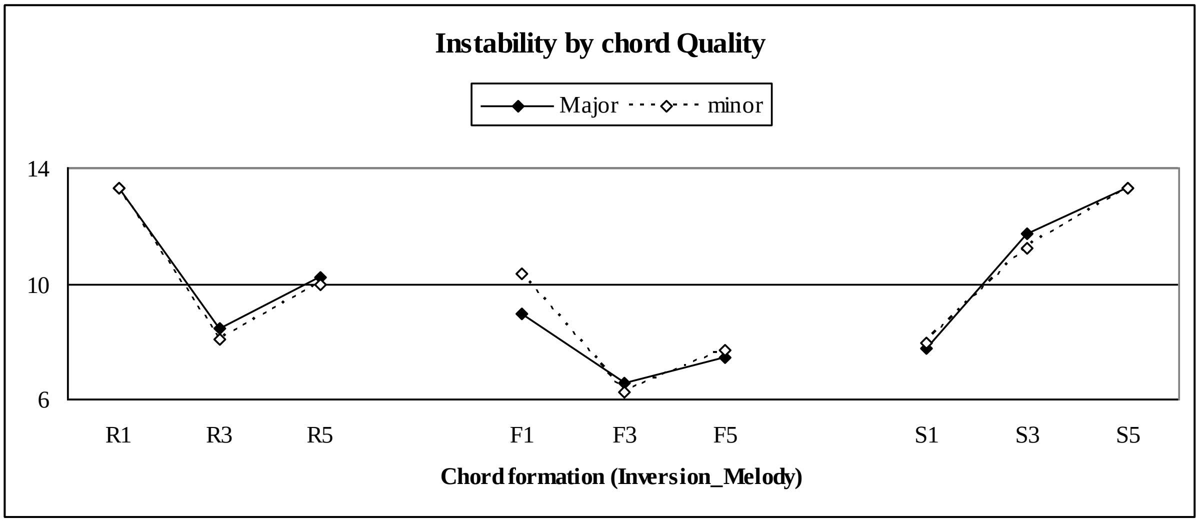

Figure 5.12. Instability values for all Major and minor Quality chord formations. Data is from Table 5.4.

Cook's Instability maps for triads do not differentiate between Major and minor Quality triads.[365] Regardless of Inversion, both are found in the areas of stability. Only augmented, diminished, and suspended fourth triads are located in the areas of instability.

SH and Inversion

ANOVA indicated, regardless of chord Quality, perceived tension was greatest for Second Inversion chords, less so for First Inversion chords, and least for Root position chords.[366] Instability values shown in Figure 5.13 tell a different story. Root position chord formations have the highest Instability value, followed by Second Inversion, with the smallest Instability value associated with First Inversion chords. These results run contrary to music theory, to Lerdahl's *Surface Tension Rule*, to our own experience, and to the ratings of participants in this study. *SH*'s Instability values do not appear to predict perceived tension due to chord Inversion.

[365] Cook (2009) does not use the same variety in chord formations as found in the present study. The stimuli in this study were tetra-chords. Cook (2009) discusses triads. According to the nomenclature for this study, the triads described in Cook (2009) would be called R5, F1, and S3.

[366] See Chapter 3.

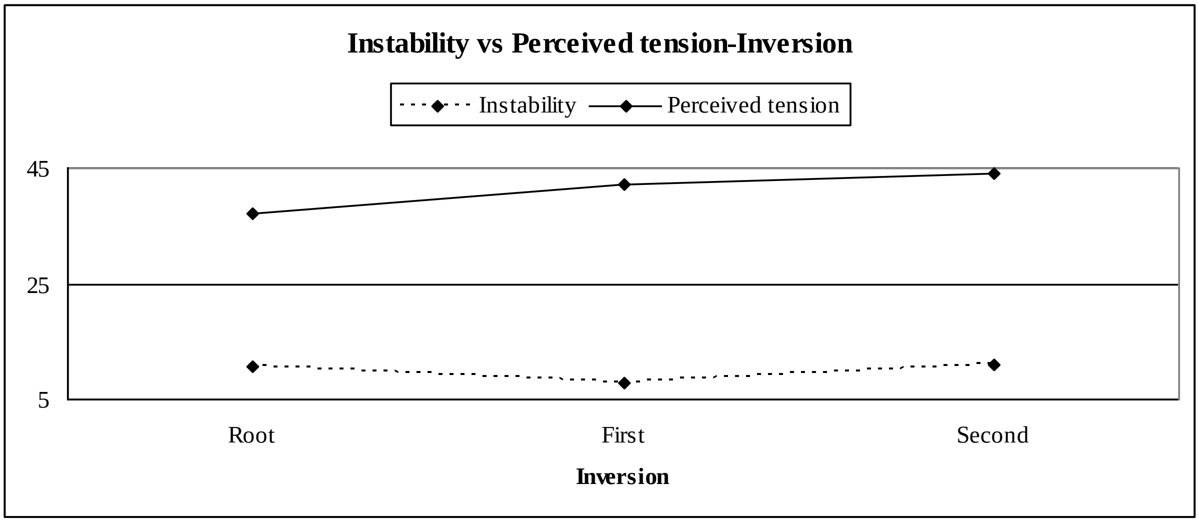

Figure 5.13. Mean Instability and mean of medians perceived tension by Inversion. See Appendix I Table I.4 for data.

Paired samples *t*-test[367] and Effect Size combined with 95% Confidence Intervals[368] showed the greatest difference in mean of medians perceived tension was between Root position and Second Inversion chords. This was followed by the difference in mean of medians between Root position and First Inversion. The smallest difference in mean of medians was between First and Second Inversion chords. Differences between Instability values do not predict differences in means of medians for chord Inversion. In fact, as the values in Table 5.5 show, the inverse of Instability values aligns with the differences in means of medians.

Table 5.5.

Differences of means of medians perceived tension, Instability, and the inverse of Instability

Comparison	Perceived tension means Difference	Instability Difference	1/Instability Difference
R & F	5.22	2.68	.37
R & S	6.94	.31	3.26
F & S	1.71	2.99	.33

Note. R = Root position, F = First Inversion, S = Second Inversion.

Calculating the inverse of the difference between Instability values is clumsy. Obtaining the inverse of the Instability value is uncomplicated and, perhaps, more useful. The inverse of Instability values (times 100 to be within the same range as Perceived tension values) predicts perceived tension for Root position and First Inversion chord formations, but not for Second Inversion chord formations. The inverse of Instability, then, appears somewhat successful in predicting perceived tension of chord formations used in this study (Figure 5.14).

[367] See Chapter 3.
[368] See Chapter 4.

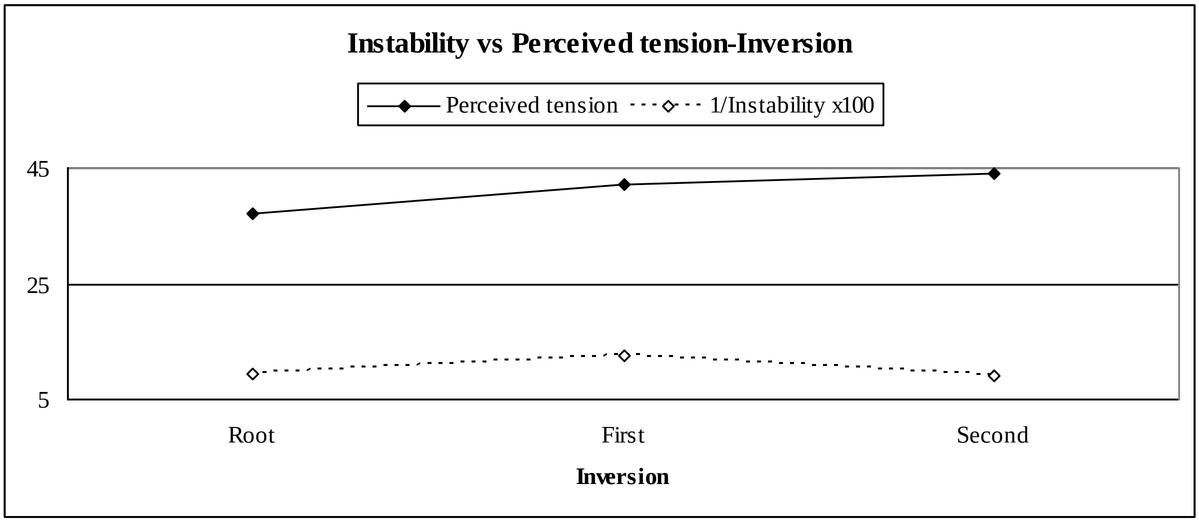

Figure 5.14. The inverse of Instability and mean of medians perceived tension by Inversion. See Appendix I Table I.5 for data.

SH and Melody

It was not surprising to discover, from the results in this study, Major Quality chords were perceived less tense than were minor Quality chords. It was not surprising to discover Root position chord formations were perceived as less tense than were First Inversion chord formations, which were perceived as less tense than were Second Inversion chord formations. It was surprising to discover Melody 1 was perceived as more tense than was Melody 3. Perhaps *SH*'s Instability can contribute to an explanation.

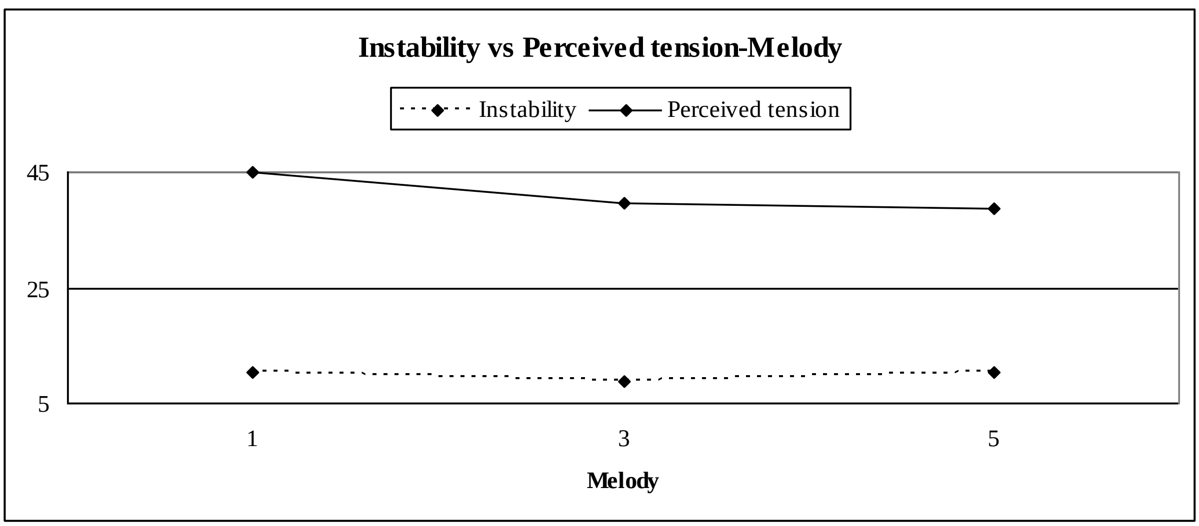

Figure 5.15. Mean Instability and mean of medians perceived tension due to Melody where 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice. See Appendix E Table E.6 for data.

The Instability value is higher for Melody 1 then it is for Melody 3. The Instability value is higher for Melody 5 than it is for Melody 1. This does not reflect the data obtained from this study where mean of medians perceived tension due to Melody 5 was lower than that due to Melody 1. The results of both a paired sample *t*-test[369] and 95% Confidence Intervals around the difference of means[370] give reason to conclude there is little difference in the perception of tension due to Melody 3 and that due to Melody 5. This is not reflected in the Instability values as the largest difference (1.62) occurs between Melody 3 (8.72) and Melody 5 (10.34).

SH and 47 Chord Formations

The default first tone in Cook's *Seeing Harmony* is 261.6 Hz (C_4). Creating chords which contain C_4 as one of the four chord tones reduces the pool of chord formations from the original 216 to 53.[371] The results discussed above consider the means of the median values from 216 chord formations. Unlike Vassilakis' *SRA*, the actual sound files are not analysed in *SH*. Perhaps, with *SH*, the mean Instability of 4 Root_Melody 1 chord formations cannot represent the mean of medians perceived tension of all 24 Root_Melody 1 chord formations used in this study, or the mean Instability of 27 minor Quality chords cannot represent the perceived tension of all 108 minor Quality chords used in this study.

Thus, the data were re-examined matching the mean of medians perceived tension for the chord formations analysed with *SH*. Table I.1 in Appendix I lists the 53 chord formations of C (8), F (10), and A^b (8) Majors, and c (8), f (10), and a (9) minors which contain the default tone C_4. There were 6 chord formations where two configurations which included C_4 were possible. Only chord formations with the same pitch frequencies (Hz) as the sound files heard by participants were considered for the present analysis. Thus, of the 53 possible chord formations, only the 47 composed of the same frequencies as the stimuli were analysed with *SH*. Table 5.6 gives the keys, chord formations, Instability (as determined by *SH*), and mean of medians tension perceived by participants in this study.

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[369] See Chapter 3.

[370] See Chapter 4.

[371] Table I.1 in Appendix I lists the 53 chord formations of C (8), F (10), and A^b (8) Majors, and c (8), f (10), and a (9) minors which contain the default tone C_4. Of the 53, only the 47 composed of the same frequencies as the stimuli were analysed with *SH*.

Table 5.6.

The 47 chord formations tested using Cook's Seeing Harmony program and mean of medians perceived tension from study participants

KEY	Chord Formation	I	PT	Chord Formation	I	PT	Chord Formation	I	PT
C	R1	-	-	F1	11.71	32.93	S1	7.23	33.22
	R3	8.81	17.08	F3	7.19	20.36	S3	11.88	26.20
	R5	10.41	46.90	F5	8.73	24.22	S5	13.36	25.65
F	R1	13.29	26.92	F1	11.19	42.52	S1	9.28	21.99
	R3	9.38	60.51	F3	7.12	29.51	S3	11.53	28.23
	R5	9.44	25.52	F5	8.99	31.90	S5	-	-
A^b	R1	13.35	16.30	F1	-	-	S1	9.7	26.01
	R3	7.17	50.27	F3	4.75	25.96	S3	-	-
	R5	10.87	28.71	F5	7.1	28.08	S5	13.3	36.35
c	R1	-	-	F1	12.15	54.89	S1	7.2	54.86
	R3	8.35	19.32	F3	7.16	52.49	S3	11.44	60.09
	R5	10.38	48.35	F5	9.16	51.40	S5	13.36	59.43
f	R1	13.29	52.75	F1	11.79	65.22	S1	9.28	52.55
	R3	8.81	26.36	F3	7.17	54.69	S3	10.97	56.71
	R5	8.87	55.16	F5	9.6	56.91	S5	-	-
a	R1	13.34	54.92	F1	7.07	47.64	S1	9.84	54.13
	R3	7.16	15.41	F3	5.49	57.09	S3	-	-
	R5	10.72	48.15	F5	7.09	51.45	S5	13.3	65.32

Note. Upper case key is Major chord Quality and lower case is minor chord Quality. Inversion: R = Root position, F = First Inversion, S = Second Inversion; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; I = Cook's Instability value; PT = mean of medians perceived tension.

The question now is whether Instability, as determined by *SH*, can predict perceived tension when the pitch frequency of the stimuli match those entered into *SH*. Pearson's correlation co-efficient (*r*) was calculated to determine the relationship between these two measures (Table 5.7). The correlation coefficients, when considering all 216 chord formations, suggest, as discussed above, *SH*'s Instability does not predict participants' perception of tension. This is confirmed by the *p*-values, which suggest there is no convincing evidence tension perceived can be predicted by Instability. The same is true when considering the 47 chord formations. Again, the correlation coefficients are weak and the high *p*-values suggest there is no evidence Instability predicts tension perceived in chords composed of the same pitch frequencies as those analysed by *SH*.

Table 5.7.

Correlation between mean of medians perceived tension and Instability determined by Cook's Seeing Harmony program

Chord	216			47		
Formation	*r*	*df*	*p*	*r*	*df*	*p*
All	.003	16	.99	.13	44	.39
Major	-.33	7	.39	-.05	21	.81
minor	.35	7	.36	.39	22	.06
Root	.13	4	.81	.15	14	.29
First	.33	4	.52	.27	15	.29
Second	-.223	4	.67	.08	12	.79
Root_minor				**.76**	**6**	**.03**
First_minor				.50	7	.17
Second_minor				-.01	5	.99
Melody 1_minor				.41	6	.31
Melody 3_minor				.18	6	.67
Melody 5_minor				.62	6	.1

Note. 216 refers to the number of chord formations used as stimuli in this study. 47 refers to the number of chord formations using the same pitch frequencies (Hz) as those analysed by Cook's *Seeing Harmony* programme.

There are two exceptions to the above generalisation suggesting there is no evidence Instability predicts tension perceived in chords composed of the same pitch frequencies as those analysed by *SH*. The first is the correlation between Instability and perceived tension of the 24 minor Quality chords (the underlined values in Table 5.7). Here we find a borderline *p*-value of .06 indicating Instability may predict tension due to minor chord

Quality.[372] The second exception is the correlation between *SH*'s Instability and the mean of medians perceived tension due to 8 Root_minor Quality chords (the bolded values in Table 5.7). These calculations reveal a relatively strong correlation between Instability and perceived tension due to Root position minor Quality chords such that 57.8% of the variance in perceived tension of minor Root position chords is explained by Instability as calculated by *SH*. An analysis of the minor Quality chords by Melody did not reveal a relationship between Instability and perceived tension. Thus, Instability, as defined by Cook's *Seeing Harmony* programme, may predict tension due to minor Quality chords, in general. Instability may be a predictor of tension due to Root position in minor Quality chords.

SH Conclusions

Cook's value for chord Instability combines Dissonance (intervallic effects) with Tension (triadic or chordal effects). Cook's research has dealt primarily with triads, and the *Seeing Harmony* programme has successfully differentiated between Instability of two categories of triads, with Major and minor Quality (and their inversions) in one category, and diminished, augmented, and suspended fourth (and their inversions) in another.[373] Presently, *Seeing Harmony* is not successful at generating Instability values for four-note chords that reflect results of perceived tension from this study. *SH* was unable to differentiate between Instability due to Inversion or due to differing Melody notes. Cook is aware of the possible limitations to his programme as he says, "there are a few complications with tetrads that might still need attention."[374] In its present form it may be possible for *Seeing Harmony* to distinguish between Instability of Major and minor four-note chords heard out of a musical and tonal context when one chord tone is C_4 (261.6 Hz). Also, under these same conditions, Instability values may predict perceived tension of four-note Root position minor Quality chords.

Lahdelma and Eerola

Lahdelma and Eerola believe more than auditory roughness contributes to listeners' experience of tension in chords heard outside of a musical or tonal context. Their study asked 418 nonmusicians (i.e. Novice) and musicians (i.e. Expert) participants to rate perceived valence (1 = negative and 7 = positive), tension (1 = relaxed and 7 = tense), energy (1 = low and 7 = high), consonance (1 = rough and 7 = smooth), and preference (1 = low and 7 = high) of two versions of 15 different chord formations. The various chord formations included Root, First, and Second Inversions of Major and minor triads as well as various tetrachords (although not Major and minor tetrachords as found in the present study), pentachords, and hexachords. All triads were in close position meaning both the lowest and highest notes changed for each chord position. In this way, Root position chords always had the root on the bottom and the fifth on the top (i.e. R5M and R5n). First inversion chords always had the third on the bottom and the root on the top (i.e. F1M and F1n). Second inversion chords always had the fifth on the bottom and the third on the top (i.e. S3M and S3n). The tetrads used in the current study allowed for each bass note to have three different melody notes (e.g. R1, R3, and R5), and each melody note to have three different bass notes (e.g. R1, F1, and S1).

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[372] A borderline *p*-value indicates repetitions of the study might result in *p*-values which suggest there is evidence Instability predicts perceived tension.

[373] Examples of the five triad types, with C as the root, used in Cook's work—Major (C-E-G-C-E-G), minor (C-E^b-G-C-E^b-G), diminished (C-E^b-G^b -C-E^b-G^b -), augmented (C-E-G$^\#$-C-E-G$^\#$), and suspended fourth (C-F-G-C-E-G).

[374] Norman Cook, email message to author, September 15, 2015.

Even allowing for these differences in stimuli, Lahdelma and Eerola's study demonstrates some interesting results which may help to clarify some of the findings of this present study.

With respect to perceived tension in Major and minor triads, Lahdelma and Eerola found perceived tension increased moving from Root position_Major, to First Inversion_Major, to Second Inversion_Major, to Root position_minor, to First Inversion_minor, to Second Inversion_minor. Perceived consonance decreased moving from Root position_Major through to Second Inversion_minor. In other words, perceived tension in Major and minor triads and their inversions correlated inversely with consonance. Root position Major triads were perceived as least tense and most consonant. While Second Inversion minor triads were perceived as most tense and least consonant. Both Major and minor triads (moving from Root through to Second Inversion) were perceived as increasing in energy. All forms of minor triads were perceived as having less energy than all forms of Major triads. These results are consistent with the results of the current study and our musical intuition.

Lahdelma and Eerola determined the effect of harmonicity, roughness, and register on their Major and minor triads. They found harmonicity to be higher in Major triads than in minor triads. Roughness was about equal for Major and minor triads as was sharpness. Unfortunately, Major triads and their inversions (and minor triads and their inversions) were taken as a group and not considered independently. Register was found to influence perception of tension, energy, and consonance. Participants in the present study anecdotally reported an effect of register in that chords in lower register were perceived as embodying less tension than the same chord formation in a high register. Lahdelma and Eerola found the same trend with their Major and minor triads.

The current study did not find a correlation between perceived tension of tetrachords and their inversions, and calculated roughness as determined by Vassilakis and Fitz's *Spectral and Roughness Analysis (SRA)* or Cook's *Seeing Harmony (SH)* programmes. Lahdelma and Eerola, when considering mean ratings for all chords in their study, did find a correlation between perceived roughness and perceived tension as rated by their participants. They also found sharpness correlated with perceived tension. Lahdelma and Eerola define roughness as "the sensory beating of the partials in the sound"[375] and sharpness as being "caused by energy at high frequencies."[376] We know roughness could not explain all the results of perceived tension for the current study. Perhaps sharpness could explain the unexpected result of the perception of Melody 1 as tenser than either Melody 3 or Melody 5.

As described above, analysis of each of the 216 chord formations by Vassilakis and Fitz's *Spectral and Roughness Analysis (SRA)* results in a roughness value. Roughness can be determined by two methods. You can instruct the programme to determine the roughness in the middle of the stimuli or at time intervals. Both methods were used for this present study.[377] Each method reports the 50 frequencies and their amplitudes descending by amplitude. Table 5.8 is an example of the roughness analysis, at the midpoint (roughly 2400ms), of First Inversion_Melody 1_a^{b} minor. These frequencies/pitches are displayed in Figure 5.16a. The frequencies for the chord formations in Figure 5.16 b) to f) were obtained in the same manner.

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375 Lahdelma and Eerola (2016), 12.
376 Lahdelma and Eerola (2016), 12.
377 While both methods were used, only the results of the 250ms intervals were reported. Like this roughness value, roughness calculated at the midpoint of the stimuli did not correlate with perceived tension.

Table 5.8.

*Frequency (Hz), Pitch, and Amplitude (m) of first 7 of 50 values reported by SRA for First Inversion_Melody 1_*a^{b} *minor*

Frequency (Hz)	Pitch	Amplitude (m)
104.38	A^{b}_{2}	.0126
247.77	C^{b}_{4}	.0125
208.59	A^{b}_{3}	.0096
419.09	A^{b}_{4}	.0072
155.34	E^{b}_{3}	.0061
835.12	A^{b}_{5}	.0046
467.54	B^{b}_{4}	.0041

Figure 5.16 a) to f) is an attempt to apply Lahdelma and Eerola's finding regarding the influence of sharpness on participants' perception of tension. They defined sharpness as the energy at high frequencies. In Figure 5.16, Amplitude, given by *SRA*, is used to represent the energy at a frequency. The bottom staff of this figure shows the pitches of the chord formation as heard by the participants in this study. The minor keys and the roughness value calculated by *SRA* are above this staff, in Italics. The numbers below the upper staff give the mean of medians of tension perceived by participants in this study. The upper staff displays the first seven frequencies with the highest amplitudes (at the midpoint, as determined by *SRA*).

Figure 5.16. Chord formation, roughness, mean of median perceived tension, first seven frequencies with largest amplitudes as determined by Vassilakis and Fitz's *Spectral and Roughness Analysis*.[378] Note. lower case is minor chord Quality. Inversion: R = Root position, F = First Inversion, S = Second Inversion; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice.

[378] I arbitrarily chose to compare the chord formations based on the lowest bass notes of the six chord formations shown. The same thing could have been done with chord formations based on the highest bass notes. I chose to compare Melody 1 and Melody 3 because it was the higher perceived tension values for Melody 1 than for Melody 3 which ran contrary to music theory, Lerdahl's *Surface Tension Rule*, and our own musical intuition.

As the results of this study and Lahdelma and Eerola's study show, roughness does not reliably predict perceived tension. Roughness values for Figure 5.16a, 5.16b, 5.16e, and 5.16f do correlate with tension values. Roughness values for Figure 5.16c and 5.16d do not. The chord formations with the highest frequencies and highest energy (amplitude) are those of Melody 1. This may seem reasonable as the highest chord note is found in R1n and F1n chord formations when compared to R3n and F3n. This does not hold true for the comparison between S1n and S3n. Here the top note of the chord formation is the same yet the frequencies with the highest amplitudes are found in S1n. The perceived tension is slightly higher for S1n than for S3n. This limited exploration of the contribution of sharpness to perceived tension as described by Lahdelma and Eerola requires a more in-depth look as it seems to show some promise in explaining the surprising result of this study showing Melody 1 as perceived as tenser than Melody 3.

The perceived tension values in the six chord samples found at Figure 5.16 seem to indicate sharpness could correlate with perceived tension embodied in the 216 chord formations heard in this study. Sharpness might explain Melody 1 perceived as tenser than Melody 3, if in fact, all Melody 1 chord formations had higher pitches than all Melody 3 chord formations. The results of this study showed, regardless of Inversion and chord Quality, the mean of medians of perceived tension was higher for Melody 1 than for either Melody 3 or Melody 5. The results also showed, regardless of Inversion and chord Quality, the mean of medians of perceived tension due to Melody 3 was not perceived differently from tension due to Melody 5.[379] Figures 5.17-5.19, showing the range of Melody notes for each Inversion of the chord formations used in this study, are accompanied by graphs, showing the mean of median perceived tension for each Inversion with each of three different Melody notes.

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[379] Paired samples *t*-test (Table 3.6) and Effect Size accompanied by 95% Confidence Interval suggest tension perceived when hearing S3 might be different than tension perceived when hearing S5.

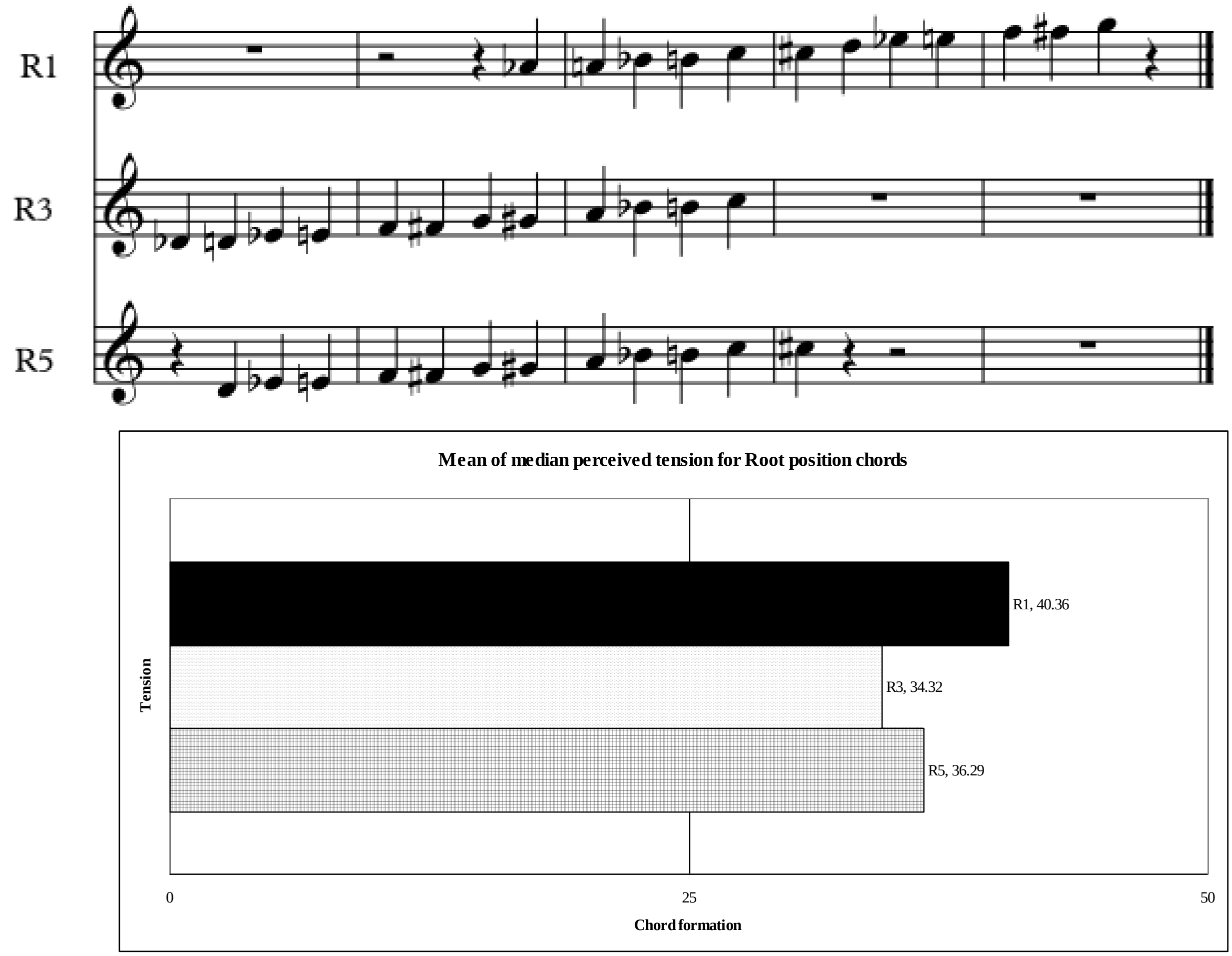

Figure 5.17. Range of Melody notes for Root position Major and minor chords and graph showing the combined mean of medians perceived tension for chord Quality of Root position chords; where R = Root position, 1 = Melody 1 (the root of the chord in the top voice of the chord), 3 = Melody 3 (third of the chord in the top voice), and 5 = Melody 5 fifth of the chord in the top voice of the chord).

As we see in Figure 5.17, the range of Melody 1 for Root position chords is seven semitones higher than the range of Melody 3, and six semitones higher than the range of Melody 5. Melody 5 goes one semitone higher than Melody 3. Otherwise the ranges of Melody 3 and Melody 5 are the same. As mean of medians perceived tension appears to mirror register, we might conclude sharpness may well explain the higher tension ratings for Melody 1 in Root position chords, and the lack of differentiation between tension due to Melody 3 and that due to Melody 5.

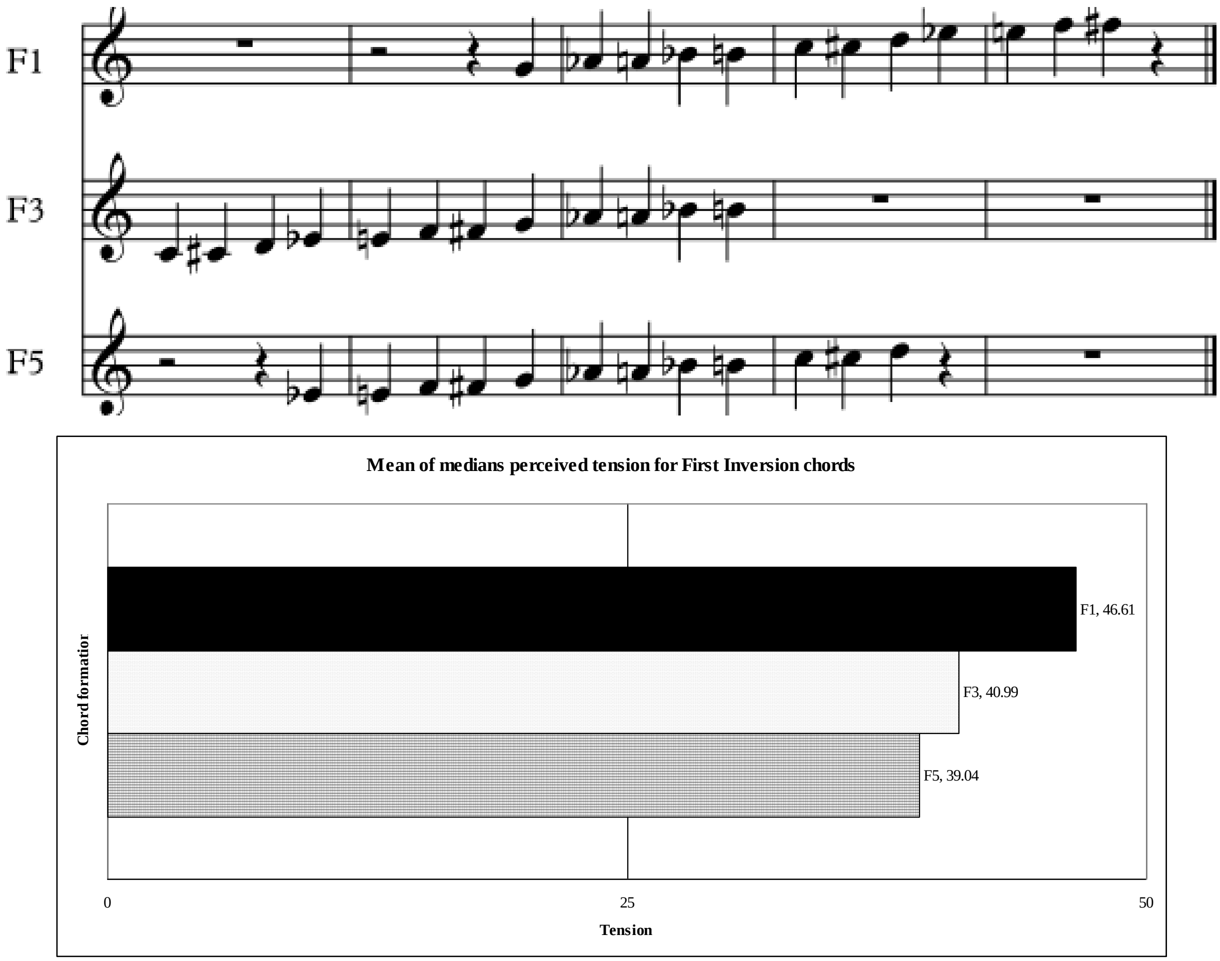

Figure 5.18. Range of Melody notes for First Inversion Major and minor chords and graph showing the combined mean of medians perceived tension for chord Quality of First Inversion chords; where F = First Inversion, 1 = Melody 1 (the root of the chord in the top voice of the chord), 3 = Melody 3 (third of the chord in the top voice), and 5 = Melody 5 fifth of the chord in the top voice of the chord).

We could draw the same conclusion regarding the effect of range on First Inversion chords (Figure 5.18). The range of Melody 1 is higher than that of Melody 3 (7 semitones) and Melody 5 (4 semitones). Melody 5 is now three semitones higher than Melody 3, although listeners did not perceive a difference in tension.[380] Once again, we may be drawn to conclude register mirrors perceived tension, except the range of Melody 3 is lower than that of Melody 5.

[380] Both paired samples *t*-test (Table 3.6) and Effect Sizes accompanied by 95% Confidence Interval (Figurer 4.11) suggest it unlikely perceived tension is different for Melody 3 and Melody 5 in First Inversion Major and minor Quality chords.

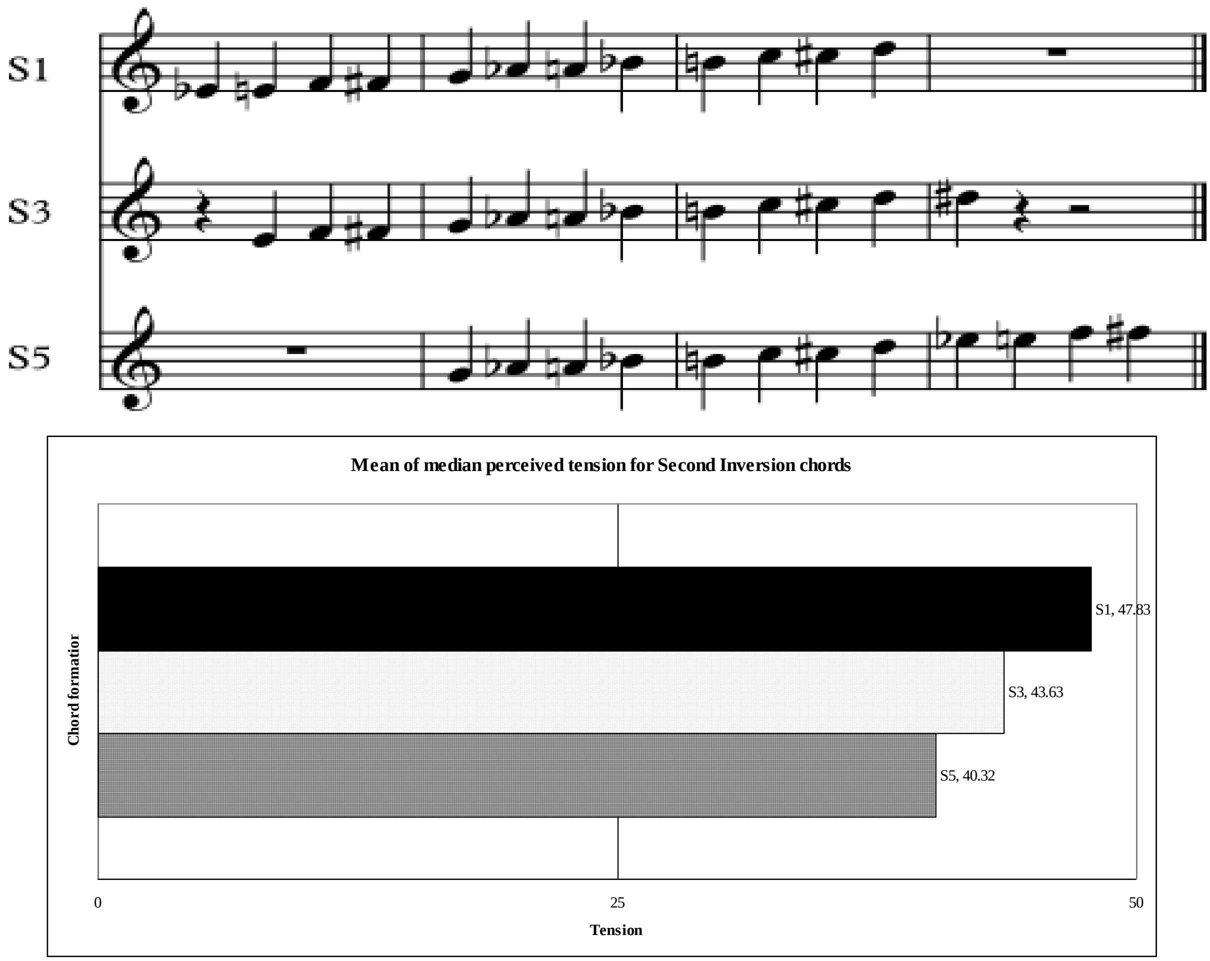

Figure 5.19. Range of Melody notes for Second Inversion Major and minor chords and graph showing the combined mean of medians perceived tension for chord Quality of Second Inversion chords; where S = Second Inversion, 1 = Melody 1 (the root of the chord in the top voice of the chord), 3 = Melody 3 (third of the chord in the top voice), and 5 = Melody 5 fifth of the chord in the top voice of the chord).

Unfortunately, the trend does not hold for Second Inversion chords. Here we see Melody 1 has the lowest range but still the highest tension values. The range of Melody 3 is one semitone higher than that of Melody 1, but the perceived tension is less. Recall, there was a difference of one semitone between R3 and R5 without a perceived difference in tension. Furthermore, the range of R1 is one semitone higher than F1, yet F1 is perceived as more tense. The range of S5 is the same as that of F1. Yet, the mean of median perceived tension is higher for F1 (46.61) when compared to S5 (40.32). The range of Melody for F5 is the same as that of S1. Once again the mean of median perceived tension is not the same. It is higher for S1 (47.83) than it is for F5 (39.04).

Figures 5.16 to 5.19 demonstrate two attempts to determine the contribution of what Lahdelma and Eerola call 'sharpness.' Figure 5.20 is another attempt to determine if 'sharpness' was contributed to the perceived tension in the sound stimuli used in this study. Figure 5.16 illustrates the five strongest frequencies, as determined by *SRA*, of six chord formations. Figure 5.20 records the first two frequencies (by amplitude) of the nine chord formations of f minor.

Table 5.9.

Chord formations for f minor, first two frequencies with respective amplitudes, and their contribution to roughness.

Chord	FR1	Amp	FR2	Amp	Rough
R1	700.52	1.87	416.05	1.28	1.94
R3	349.82	1.43	524.82	0.90	32.65
R5	350.40	1.37	415.96	1.14	1403.60
F1	350.50	1.96	700.68	1.95	0.30
F3	208.40	1.88	350.06	1.84	125.39
F5	350.06	1.84	208.42	1.53	95.01
S1	208.56	2.06	350.37	1.36	62.05
S3	350.06	1.69	416.59	1.12	931.27
S5	208.56	2.04	350.06	1.79	107.72

Note. R = Root position, F = First Inversion, S = Second Inversion; 1 = Melody 1 (root of chord in top voice), 3 = Melody 3 (third of chord in top voice), 5 = Melody 5 (fifth of chord in top voice); FR1 = first frequency (Hertz) as determined by amplitude using *Spectral and Roughness Analysis*, FR2 = second frequency (Hertz) as determined by amplitude using *Spectral and Roughness Analysis*; Amp = Amplitude (x100) as determined by amplitude using *Spectral and Roughness Analysis*, Rough = the contribution of the interaction of FR1 and FR2 to the roughness of the sound using *Spectral and Roughness Analysis*. Note. Unlike the values reported in Figure 5.16 and Appendix H, these values come from the median of five roughness values taken at or near the midpoint of the sound file.

Once again, there appears to be no consistent relationship between high frequency/large amplitude and roughness. Regardless of Inversion, in comparison to Melody 3 and Melody 5, Melody 1 has highest first and second frequencies coupled with greatest amplitudes. Yet, contrary to the results in chapters 3 and 4 (where the perception of tension was higher for Melody 1 than for either Melody 3 or Melody 5), the contribution of these strongest two frequencies results in the lowest roughness values for Melody 1 when compared to those of Melody 3 and Melody 5. *SRA* analysis of 50 peaks of frequency and amplitude for Melody 3 and Melody 5 do show the presence of higher frequencies but their amplitudes are much smaller. Using the frequency 700.52 Hz as an example, the amplitude in R1 is 0.01871586; in R3 the amplitude is .00552517; in R5 the amplitude is .0056694.

Conclusions

This study requires participants to rate perceived level of tension when listening to 9 versions of Major and minor four-note chords (3 Inversions and 3 Melody notes) heard out of a musical and tonal context. Major Quality chords, in general, are perceived as less tense than are minor Quality chords. Regardless of chord Quality, Root position is perceived as less tense than is First Inversion, which is perceived less tense than Second Inversion. Expertise did not affect participants' perception of tension. Surprisingly, regardless of Inversion or chord Quality, chords with the root in the Melody (Melody 1) are perceived as embodying more tension then when the third of the chord was in the Melody (Melody 3), or when the fifth of the chord was in the Melody (Melody 5). This result is contrary to the tenets of music theory, to Lerdahl's predictions, and to our own experiences of Western tonal music.

The possibility of other factors contributing to the results were considered by examining the effects of the length of the Disruptor Sequences, Melodic Attraction between the upper note of the Disruptor Sequence and upper note of the target chord, Melodic Attraction between the upper and lower notes of the Disruptor Sequences and the upper and lower notes of the target chord (Harmonic Attraction), Vassilakis and Fitz's *Spectral and Roughness Analysis*, Cook's *Seeing Harmony*[381], and sharpness (Lahdelma and Eerola).

This investigation into other possible factors revealed the length of the Disruptor Sequences did not contributed to perceived tension of the stimuli used in this study. Melodic Attraction between the highest note of the Disruptor Sequence and the upper note of the target chord did not contribute to perceived tension of stimuli heard in this study. Nor did Harmonic Attraction between the lower and upper notes of the Disruptor Sequence and the lower and upper notes of the target chord contribute to perceived tension of target chords used in this study.

Surprisingly, auditory roughness, as determined by Vassilakis and Fitz's *Spectral and Roughness Analysis*, did not predict participant's perception of tension of the chords heard in this study. *SRA* provided roughness values due to the interactions of 50 partials for each of the 216 four-note chord formations. The median of 15-18 roughness calculations, taken at 250ms intervals during each of the 4s sound file, was unsuccessful in reliably predicting participants' experience of tension embodied in the nine Major and nine minor chord formations.[382]

Cook's *Seeing Harmony* successfully differentiates between Instability of two categories of triads; Major and minor triads (and their inversions) are in one category, augmented, diminished, and suspended fourth triads (and their inversions) are in another. It is not sensitive enough, however, to differentiate between Instability of Major and minor triads (and inversions). Nor can Instability predict perceived tension embodied in the Major and minor four-note chords used in this study. *SH* is unable to predict perceived tension due to chord Inversion, Melody, and/or chord Quality when compared to all 216 chord formations. *SH* cannot predict perceived tension due to chord Inversion, Melody, and/or chord Quality when compared to 47 chord formations composed of the same pitch

[381] Although not reported in this paper, other explanations, including spectral pitch similarity and harmonicity, were explored. Spectral pitch similarity of chord tones is determined by the interaction of the partials of each chord tone. High spectral pitch similarity occurs when the partials of one tone are found in or are not in conflict with the partials of another tone. For example, C_3 and C_4 would have high spectral pitch similarity as the first five partials of C_3 (C_3, C_4, G_4, C_5, and E_5), are of the same pitch class as and share two partials with the first five partials of C_4 (C_4, C_5, G_5, C_6, and E_6). C_3 (C_3, C_4, G_4, C_5, and E_5) and G_3 (G_3, G_4, D_5, G_5, and B_5) have a lower spectral pitch similarity as they share one pitch class and one partial. Even lower still is the spectral pitch similarity between C_3 (C_3, C_4, G_4, C_5, and E_5) and D_3 (D_3, D_4, A_4, D_5, and $F^{\#}_5$). These tones share no pitch classes. The amplitude of each partial is also considered in determining spectral pitch similarity. No trend of spectral pitch similarity was determined when comparing the first twelve partials and their amplitudes (as determined by Vassilakis and Fitz's *Spectral and Roughness Analysis*) across the 18 chord formations used as stimuli in this study.
Harmonicity is a measure of how closely the partials of the tones align with the harmonic spectrum of a complex tone. The harmonic spectrum in question consists of partials which are integer multiples of the fundamental frequency. Because of the manner in which the sound stimuli were made, it was not possible to determine harmonicity among each chord tone. It was possible, once again using the partials and corresponding amplitudes from *SRA*, to determine the harmonicity of each chord. As with spectral pitch similarity, there was no consistent characteristic harmonicity for Inversion, Melody, or chord Quality. Lahdelma and Eerola (2016) found "harmonicity did not exhibit statistically significant correlations with any of the five dimensions [perceived valence, tension, energy, consonance, and preference]." (p. 14) See Milne, Laney, and Sharp (2016) for more detailed information on spectral pitch similarity and harmonicity. Also see Plack (2010) for information on harmonicity.
[382] The nine chord formations, for each chord Quality, were Root_Melody 1, Root_Melody 3, Root_Melody 5, First_Melody 1, First_Melody 3, First_Melody 5, Second_Melody 1, Second_Melody 3, and Second_Melody 5.

frequencies as those analysed by the programme. It may be possible for *Seeing Harmony* to distinguish between Instability of Major and minor four-note chords heard out of a musical and tonal context when one of four chord tones is C_4 (261.6 Hz). Also, under these same conditions, Instability values may predict perceived tension of four-note Root position minor Quality chords.

Spectral and Roughness Analysis and *Seeing Harmony*, like Lerdahl's *Surface Tension Rule*, are concerned with perception of chords heard out of musical and tonal context. The results of this study, when compared with *SRA* and *SH*, support Vassilakis and Cook when they suggest there is more involved in the perception of four-note chords than can be explained by auditory roughness (*SRA*), based on the effects of intervals, or Instability (*SH*), based on interval effects together with chordal effects.

Somewhat promising is Lahdelma and Eerola's theory of the contribution energy of high frequencies or sharpness to the perception of tension in chords heard devoid of a musical or tonal context. A preliminary and rudimentary application of this idea to some of the data obtained in this study shows promising results. It could be instructive to analyse the sound files used in this study to determine the contribution of sharpness as sharpness may help to explain why—contrary to music theory, Lerdahl's *Surface Tension Rule*, and our musical intuition—chord formations with the root in the Melody (Melody 1) were perceived as more tense than chords with the third (Melody 3) or the fifth (Melody 5) in the Melody.

CHAPTER 6: MODIFICATIONS TO LERDAHL'S *SURFACE TENSION RULE*

Introduction

In 2001, Lerdahl published *Tonal Pitch Space*. Included in this monograph is his model for predicting tension perceived at each musical event in a piece of Western tonal music. Lerdahl's model, based on tenets of music theory and empirical data from research into music perception, quantifies tension experienced by listeners familiar with Western tonal music. Using the musical score as a visual representation of the auditory experience, Lerdahl calculates tension for each musical event based on the sequential and hierarchical contributions of melodic, harmonic, and rhythmic elements, as well as the psychoacoustic characteristics of the chords.

Many aspects of the model rely on the hierarchy of pitches, chords, and regions established in the context of Western tonal music. One aspect, surface tension, does not. In his *Surface Tension Rule*, Lerdahl attributes tension due to chord Inversion, Melody note, and non-chord tones, to the acoustical features inherent in the notes themselves. He is suggesting the contribution of chord Inversion, Melody note, and nonchord tones do not rely on a musical or tonal context.[383]

Lerdahl considers tension due to instability of chord Inversion to be greater than tension due to instability of Melody note.[384] Chords in Root position have no value added due to tension. Chords in First and Second Inversion receive an added tension value of 2. Similarly, chords with the root in the Melody have no value added due to tension, while chords with either the 3^{rd} or 5^{th} of the chord in the Melody receive an added tension value of 1. Diatonic non-chord tones receive an added tension value of 3, chromatic non-chord tones receive an added tension value of 4, and 7^{ths} receive an added tension value of 1.

According to Lerdahl, then, chords with the root in the bass or in the Melody are equally stable adding no tension. Tension due to the instability of added 7^{ths} is equivalent to tension due to the 3^{rd} or 5^{th} of the chord in the Melody. A 3^{rd} or 5^{th} in the bass is the more unstable, reflected in the tension added value of 2.[385] Adding the most tension, and assigned the highest tension added values, are non-chord tones. One of the purposes of this study was to

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[383] Chord tones, in Western tonal music, occur as intervals of octaves, sixths, fifths, fourths, and thirds. Thus, intervals of seconds and sevenths are easily identified as nonchord tones by listeners familiar with Western tonal music. For example, G in the context of F-A-C-G is easily identified as not belonging with F-A-C. Although C-G is a fifth and thus suggesting two chord tones, G forms a second with F and a seventh with A, confirming its nonchord status. In some cases, however, musical context can be necessary for the listener to distinguish between chord and nonchord tones. Rameau's *double emploi* (Chapter 1) is a good example. In the context of C major, is F-A-C-D heard as ii^6 (F-A-D) with an added 7th (C) or IV (F-A-C) with an added 6th (D)? The chords before and after F-A-C-D as well as the movement or resolution of the tones in the chord will aid the listener in deciding between the two possibilities. This study requires participants to rate perceived tension embodied in Major and minor four-note chords. This can be done, as Lerdahl maintains, devoid of a musical and tonal context.

[384] Capital letters for Inversion, Melody, chord Quality, and Expertise identify them as the four factors in this study. Similarly, capital letters for Root, First, Second, and Major identify them as levels of factors in this study. While minor is also a level in this study, it begins with a lower case letter following the tradition of identifying minor chords and regions with lower case letters.

[385] In his *Surface Tension Rule*, Lerdahl identifies three categories of surface tension—Inversion, Melody, and nonchord tones—based on their relative stability. The interaction of Inversion and Melody (two of four factors tested in this study) generates four levels of tension. Moving from most to least stable (or least to most tension added) are Root_Melody 1 (0 + 0 = 0), Root_Melody 3 or Melody 5 (0 + 1 = 1), First or Second Inversion_Melody 1 (2 + 0 = 2), and First or Second Inversion_Melody 3 or Melody 5 (2 + 1 = 3).

investigate the accuracy[386] of the tension added values for Inversion and Melody, and recommend any modifications deemed necessary by the results of this study.

In this study, eighty-two musicians (60 women, 22 men; 41 Novice and 41 Expert) rated perceived tension in 216 four-note chords (108 Major, 108 minor) presented with Steinway grand piano sound coupled with a synth pad sound. Disruptor sequences, using only the Steinway grand piano sound, flanked target chords to prevent hierarchical tonal associations between chords.

Participants heard a disruptor sequence, a 2s silence, and a four-note target chord for 4s.[387] This target chord was followed by another 2s silence during which participants recorded their rating. The same disruptor sequence followed. After a 1s silence, the process was repeated for each of the 216 target chords, each flanked by their associated disruptor sequence.

The disruptor sequences began 1 or 2 semitones below the lowest tone of the target chord, ascended, and ended 1 or 2 semitones above the highest tone of the target chord. This sequence was based on the major pentatonic scale formed on the tone a tritone away from the root of a major chord, and a tritone away from the third of a minor chord. This results in a disruptor sequence that has no tones in common with its associated target chord.

The four-note target chords (soprano, alto, tenor, and bass) were created in both open and close positions with differing soprano notes (identified as 'Melody') and differing bass notes (identified as 'Inversion'). The notes of the soprano and bass each could be one of three possibilities—the root of the chord (labelled as 1 for Melody and R for Inversion), the third of the chord (labelled as 3 for Melody and F for Inversion), or the fifth of the chord (labelled as 5 for Melody and S for Inversion). The range of pitches was from F_2 (87.31 Hz or the space below bottom line of the bass staff) to G_5 (783.99 Hz or the space above the top line on the treble staff). Following traditions of music theory, the distance between the successive voices was no more than an octave. The chords were transposed into all major and minor keys resulting in 216 chords. The chords were divided into 6 blocks of 36 chords, and presented with 3 minute rest periods between blocks. The chords within the blocks were presented in random order. The presentation order of the blocks was also randomised in the manner of Latin squares

Implications of Results

Table 6.1 summarises the means of medians perceived tension for the levels of the three factors—Inversion, Melody, and Quality.[388, 389] According to Lerdahl's *Surface Tension Rule*, the tension added value for Root position and Melody 1 is 0. The means of the medians for the levels Root position (36.99) and Melody 1 (44.93) indicate the tension perceived for the two levels is not 0. The difference between the means of medians perceived tension (7.94) suggests it is unlikely the tension added values should be the same for Root position and Melody 1. Indeed, a two-tailed paired samples t-test shows there is a difference in tension perceived between these levels, $t(81) = 10.82$, $p <$

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[386] By accuracy I mean, do Lerdahl's tension added values represent listeners' experience?

[387] While some target chords were in close position (2 of 18), the majority of target chords were in open position (16 of 18).

[388] Non-normally distributed Major chords were right skewed indicating low tension ratings. Non-normally distributed minor chords were skewed left indicating high tension ratings. Because the data were skewed, the median rather than the mean was chosen to measure the central tendency of the data. Skewness was not eliminated with removal of outliers or with various types of data transformation. See Appendices A and B for more detail.

[389] The Between subjects factor Expertise is not included as ANOVA (chapter 3) and Effect Size with 95% Confidence Intervals (chapter 4) showed no effect of Expertise.

.00001. Since the differences between these means suggest they are perceived with differing levels of tension we can draw two conclusions—*tension added values for Root position and Melody 1 are not 0, nor are they equal*.

Missing completely from Lerdahl's *Surface Tension Rule* is tension due to chord Quality. This suggests the tension added value for this factor should be 0. The means of the medians for Major (27.07) and minor Quality chords (55.02), plus the results from ANOVA (chapter 3) and Effect Size with 95% Confidence Intervals (chapter 4) indicate a *tension added value for chord Quality should be added to Lerdahl's model*. The means of medians from Table 6.1 suggest Major should have a smallest tension added value and minor should have the largest.

Table 6.1.

Means of medians perceived tension due to levels of within subjects levels

Factor	Level	Mean	SD
Inversion	Root	36.99	14.01
	First	42.22	13.88
	Second	43.93	13.70
Melody	1	44.93	16.45
	3	39.65	13.43
	5	38.55	12.90
Quality	Major	27.07	14.89
	minor	55.02	16.71

Note. Mean = mean of medians perceived tension; SD = standard deviation.

Should Root position and Major Quality be assigned the same 0 value? Recall, Lerdahl does not assign any added tension value for chord Quality suggesting there is no effect. The difference between these means (9.92) is slightly greater than the difference between Root position and Melody 1 (7.94). As stated above, a two-tailed paired samples *t*-test determined tension due to Root position was not the same as tension due to Melody 1. Another two-tailed paired samples *t*-tests *suggests tension due to Root position is not the same as tension due to Major chord Quality*, $t(81) = 15.18$, $p < .0001$. Clearly, Root position, Melody 1, and Major chord Quality cannot all have a tension added value of 0. The means of the medians perceived tension indicate Major is perceived as less tense than Root position, which is perceived as less tense than Melody 1.

Lerdahl assigns a tension added value of 2 for both First and Second Inversions predicting tension perceived is the same for these chord positions. We know from the two-tailed paired samples *t*-test reported in Table 3.3, participants perceived differing levels of tension between these Inversions, $t(81) = -2.53$, $p < .05$. Table 6.1 shows Second Inversion is perceived as tenser than First Inversion. *Tension due to First Inversion is not the same as tension due to Second Inversion.*

Lerdahl predicts tension perceived due to Melody 3 is equivalent to that due to Melody 5, and assigns a tension added value of 1 for both. Also reported in Table 3.3 is the two-tailed paired samples *t*-test, indicating participants did not perceive differing levels of tension between Melody 3 and Melody 5, $t(81) = 1.28$, $p > .05$. *The tension added value for Melody 3 and Melody 5 can be the same.*

Lerdahl, assigning a tension added value of 2 for Inversion and 1 for Melody, predicts tension added due to Inversion (First or Second) is greater than tension added due to Melody (3 or 5). The results in Table 6.1 support this prediction, as the means of the medians of First and Second Inversion are larger than those for Melody 3 and Melody 5. *The tension added value due to First and Second Inversion should be larger than the tension added value assigned to Melody 3 and Melody 5.*

Lerdahl, assigning a tension added value of 2 for Second Inversion and 0 for Melody 1, predicts tension perceived due to Second Inversion is greater than tension perceived due to Melody 1. A two-tailed paired samples *t*-test does not support this directive, $t(81) = 1.11$, $p = .27$. *Tension perceived due to Second Inversion is not different from tension perceived due to Melody 1*.[390]

Methods of Modifying Tension Added Values[391]

Lerdahl arbitrarily quantified tension due to three levels of Inversion (0 for Root, 2 for First and Second) and three levels of Melody (0 for 1, 1 for 3 and 5). He does not assign any tension added due to chord Quality. The results of this study indicate Lerdahl's assigned values require modification.

Ranking

One approach is to modify Lerdahl's hierarchical categories listed above by ranking the means of medians for each of the 7 levels. The level with the lowest perceived tension, Major, could be given a value of 1, and the level with the most tension, minor, a value of 8.[392] This approach is recorded in the column of Table 6.2 labelled Rank-1.

However, we know from data analysis, that Melody 3 and Melody 5 are not perceived as embodying different levels of tension, $t(81) = 1.28$, $p > .05$. The column in Table 6.2 labelled Rank-2 reflects this finding as both Melody 3 and Melody 5 are ranked 3rd.[393]

The means of the medians for Root and Melody 5 are quite close as well. However, a two-tailed paired samples *t*-test indicates participants perceived differing levels of tension for these two levels, $t(81) = 2.17$, $p = .03$. Thus, it is necessary to give Root and Melody 5 different rankings, 2 and 3 respectively. The same holds true for perceived level of tension between Root and Melody 3, $t(81) = 3.16$, $p = .002$. Because Melody 3 and Melody 5 are given the same Ranking, Root and Melody 3 are ranked the same as Root and Melody 5, 2 and 3 respectively.

Finally, the means of the medians of Second Inversion and Melody 1 are close together. However, in this case, the two-tailed paired samples *t*-test indicates participants did not perceive a significant difference in the tension embodied in Second Inversion and Melody 1, $t(81) = 1.11$, $p > .05$. Second Inversion and Melody 1 receive the same Ranking, 5. The column in Table 6.2 labelled Rank-Final reflects the results of the two-tailed paired samples *t*-tests.

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390 Tension added values due to the interaction of factors and levels are not considered for two reasons. Firstly, Lerdahl's *Surface Tension Rule* considers each level separately. More importantly, the results of this study showed, while some interactions affected participants' perception of tension, the effect was very small. The effects due to Inversion, Melody, and chord Quality were stronger. (See Table 3.2)

391 Four methods of modifying Lerdahl's tension added values are discussed. They are Ranking, Ratio, Regression, and Portion. Like the factors (Inversion, Melody, and Quality) and their levels, the four methods begin with upper case letters. This allows for ease of identification in the text.

392 The lowest value is not 0 as Major is perceived as embodying some tension. ANOVA (chapter 3) and Effect Size with 95% Confidence Intervals (chapter 4) indicate there is some tension perceived when hearing Major chords.

393 A thorough discussion of the effectiveness of the four approaches to modifying Lerdahl's tension added values, with reference to the seven aspects requiring modification, follows this general discussion of each approach.

Table 6.2.

Ranking among levels of factors from lowest to highest perceived tension

Factor	Level	Mean of medians	Rank-1	Rank-2	Rank-Final
Inversion	Root	36.99	2	2	2
	First	42.22	5	4	4
	Second	43.93	6	5	5
Melody	1	44.93	7	6	5
	3	39.65	4	3	3
	5	38.55	3	3	3
Quality	Major	27.07	1	1	1
	minor	55.02	8	7	6

Note. Inversion: Root = Root of chord in the bass, First = 3rd of chord in bass, Second = 5th of chord in bass; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

While Ranking is useful, it is misleading. Root is ranked 2 and First Inversion is ranked 4, perhaps implying First Inversion was twice as tense as Root position. This conclusion is not supported by the ratio of their means of medians. The mean of medians for First Inversion (42.22) is not twice the mean of medians for Root (36.99). The mean of medians for 6th ranked minor chord Quality (55.02) is not three times that of 2nd ranked Root (36.99) or twice as large as either 3rd ranked Melody 3 (39.65) or Melody 5 (38.55). The only information obtainable from Ranking is that one level is perceived as more or less tense than another level. Tension added values determined by Ranking reflect order but not relationships. Thus, from this partial discussion, it seems Ranking has limited usefulness and is not helpful in modifying Lerdahl's tension added values. A more detailed discussion follows the presentation of three other methods (Ratio, Regression, and Portion) of modifying Lerdahl's tension added values.

Ratio of Means of Medians

Perhaps a better way to modify Lerdahl's tension added values is to calculate ratios. Table 6.3 shows the results, in real numbers, when the mean of medians perceived tension for each level is compared with the lowest mean of medians perceived tension, Major Quality chords. Both Ranking and Ratio reveal tension perceived in chords with Melody 1 is closer to tension perceived in minor Quality chords than to tension perceived in Major Quality chords. Ranking only tells us tension perceived in minor Quality chords is much higher than tension perceived in Major Quality chords. Unlike Ranking, tension added values determined by Ratio indicate an explicit relationship between the levels. For example, Ratio tells us tension perceived in minor Quality chords is twice that perceived in Major Quality chords while Ranking tells us only that perceived tension is greater for minor Quality chords than it is for Major Quality chords. The range of values obtained by Ratio (1 to 2.03) is smaller than the range of values obtained by Ranking (1 to 6). This aspect becomes important when using modified values to calculate surface tension as part of Sequential or Hierarchical tension (see Surface Tension, Local Tension, and Global Tension, below).

As mentioned above, paired sample *t*-test indicates tension added due to Melody 3 and Melody 5 is perceived as being the same. While the values obtained by Ratio are not identical, they are close. We also know tension added due to Root position is not the same as that due to either Melody 3 or Melody 5. This is reflected in the values determined by Ratio. Paired samples *t*-test determined tension perceived due to Second Inversion is the same as that due to Melody 1. Once again, values determined by Ratio are close but not identical.

Ratio appears to align fairly well with these aspects of Lerdahl's *Surface Tension Rule* that require modification. The values determined by Ratio provide more specific information, than does Ranking, regarding the relationships between the levels of the factors. As with the partial discussion of the usefulness of Ranking to determine new tension added values, a more complete examination of the usefulness of Ratio follows the presentation of two other methods (Regression and Portion) of modifying Lerdahl's tension added values.

Table 6.3.

Mean of medians perceived tension of all levels compared with mean of medians perceived tension of Major chord Quality[394]

Factor	Level	Mean of medians	Ratio	Rank-Final
Inversion	Root	36.99	1.37	2
	First	42.22	1.56	4
	Second	43.93	1.62	5
Melody	1	44.93	1.66	5
	3	39.65	1.46	3
	5	38.55	1.42	3
Quality	Major	27.07	1	1
	minor	55.02	2.03	6

Note. Inversion: Root = Root of chord in the bass, First = 3rd of chord in bass, Second = 5th of chord in bass; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Ratio (expressed in real numbers) = Level Mean of medians/Major Mean of medians; Rank-Final from Table 6.2.

Bivariate Linear Regression

Bivariate Linear Regression[395] is a statistical method for determining relationships between variables. This type of data analysis, in which change in one variable is used to predict change in other variables, results in the following general equation—$y = mx + b$.[396] It might be possible to obtain new tension added values by determining

394 See Table J.5 in Appendix J for Mean of medians perceived tension of all levels compared with mean of medians perceived tension of minor chord Quality. The values, while lower than those obtained from ratio to Major chord Quality, are still too high.

395 For the remainder of this paper I will refer to Bivariate Linear Regression as Regression.

396 *y* is the unknown or dependent variable, *x* is the known or independent variable, m is the slope of the Regression line which is the best fit for the data. The slope indicates the rate of change in the dependent variable with change in the independent variable. The intercept (*b*) is the value of the dependent variable (*y*) when the independent variable (*x*) is 0.

the relationship between the means of medians perceived tension for each level and the mean of medians perceived tension in minor Quality chords.[397] The equation for the Regression performed on the data in this study is:

perceived tension of minor Quality chord = (slope)(perceived tension of level *x*) + intercept.

The results are found in Table 6.4. The *p*-values for the *F* statistic indicate there is an association between tension perceived when hearing minor Quality chords and tension perceived when hearing the other levels. The correlation coefficients (*r*) are positive indicating as perceived tension increases (or decreases) in minor Quality chords it also increases (or decreases) in all other levels. Perceived tension due to minor Quality chords correlates most strongly with tension perceived due to Second Inversion and least strongly with tension perceived due to Major Quality chords. This should not be surprising as minor Quality chords received the highest mean of medians perceived tension and Major Quality chords received the lowest mean of medians perceived tension. However the paired samples *t*-test shows tension due to Second Inversion is not perceived differently from tension due to Melody 1. This is not reflected in the Regression values.

Table 6.4.

Results of Regression of minor chord Quality on other levels

Factor	x	$r(80)$	r^2	$F(1, 80)$	b	$t_b(80)$	m	$t_m(80)$
Inversion:	Root	.78	.609	124.69*	20.59	6.25*	.93	6.25*
	First	.85	.722	207.5*	11.86	3.76*	1.023	14.4*
	Second	.842	.71	195.35*	9.89	2.92**	1.027	13.98*
Melody:	Melody 1	.797	.63	139.29*	18.64	5.68*	.81	11.8*
	Melody 3	.809	.654	51.299*	15.12	4.42*	1.006	12.3*
	Melody 5	.799	.638	140.82*	15.13	4.27*	1.035	11.87*
Quality:	Major	.412	.17	16.37*	45.5	12.05*	.462	4.046*

Note. x = the independent variable; r = Pearson's correlation coefficient; r^2 x 100 = proportion of variance in minor Quality chord accounted for by level x; F = test of significance of Regression and correlation coefficients; b = intercept or value of minor when level x is 0; t_b = test of significance of intercept b; m = slope or rate of change of minor Quality as level x changes; t_m = test of significance of slope m; $^*p < .001$, $^{**}p < .005$.

The *p*-values for the *t* statistics (for the intercept *b* and the slope *m*) indicate neither the intercept nor the slope is 0. The rate of change (*m*) of perceived tension is more rapid for Melody 5 when compared with minor Quality chords than is the rate of change of perceived tension for Major Quality chords.

The correlation coefficients and rate of change information obtained through Regression is somewhat useful in understanding the relationship between tension perceived due to minor Quality chords and tension perceived due to the other levels. The best use of the Regression results is to create equations which quantify perceived tension changes for each level as perceived tension changes for minor Quality chords. The results in Table 6.4 produce the following equations, which also include the Standard Error of the Estimate (+/-). This term gives the average

[397] I chose minor Quality chords because this level had the highest mean of medians perceived tension.

distance data points are from the fitted Regression line and represents the accuracy of the fitted line. Smaller values indicate greater accuracy as data points are closer to the fitted line.[398]

Eq. 1: minor = .93(Root) + 20.59 (+/- 10.51)

Eq. 2: minor = 1.023(First) + 11.86 (+/- 8.87)

Eq. 3: minor = 1.027(Second) + 9.89 (+/- 9.06)

Eq. 4: minor = .81(Melody 1) + 18.64 (+/- 10.16)

Eq. 5: minor = 1.006(Melody 3) + 15.12 (+/- 9.89)

Eq. 6: minor = 1.035(Melody 5) + 15.135 (+/- 10.12)

Eq. 7: minor = .462(Major) + 42.503 (+/- 15.32)

Lerdahl's *Surface Tension Rule* proposes both Root position and Melody 1 have a tension added value of 0. If 0 is substituted for Root position in equation 1, the result is a tension added value for minor Quality chords of 20.59 (+/-10.51). If 0 is substituted for Melody 1 in equation 4, the result is a tension added value of 18.64 (+/-10.16) for minor Quality chords.[399] Lerdahl assigns a tension added value of 2 for First (equation 2) and Second (equation 3) Inversion resulting in tension added values of 13.9 (+/-8.87) and 11.94 (+/-9.06), respectively, for minor Quality.[400] The reason for these wide ranging tension added values for minor Quality (11.94 to 20.59) is due not only to the relationships described by Regression, but also to Lerdahl's suggested tension added values.[401]

It is perhaps more useful to determine the lowest value for minor Quality chords which gives the lowest positive value for all levels. Through trial and error, a value of 19.75 for minor Quality chords meets these criteria, i.e., 19.75 returns the lowest positive values for all levels. [402] The tension added values derived from Regression equations, when 19.75 is substituted for minor Quality chords, are found in Table 6.5. The resulting tension added values are of a larger range (.246 to 9.345) than those derived through Ratio (1 to 2.03) and Ranking (1 to 6).

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[398] Other than the Standard Error of the Estimate for Major Quality, the accuracy for the fitted line for all levels is around 9 or 10. The fitted line for Major Quality is the least accurate. The most accurate is First Inversion.

[399] minor = .93(Root) + 20.59. If Root = 0, minor = 20.59. minor = .81(Melody 1) +18.64. If Melody 1 = 0, minor = 18.64.

[400] The Regression coefficients for Root and Melody 1 did not arrive at the same value for minor. It is possible, however, by taking the Standard Error of the Estimate around the predicted value of minor into account, Root (20.59 +/-10.51) and Melody 1 (18.64 +/- 10.16) could have the same value of 0. The same is true for the predicted value of minor when the value assigned First and Second Inversions is also the same (2).

[401] Using the results of the linear Regression, minor = .462(Major) + 42.503. Inserting the mean of median perceived tension for Major (27.07) gives a mean of median perceived tension value of 55.009. The actual value is 55.02. Similarly, minor = .81(Melody 1 = 44.93) + 18.642 = 55.03.

[402] For example, if minor = .462(Major) + 42.503, then Major = (minor/.462) - 42.503. Then, inserting 19.75 for minor, Major = (19.75/.462) - 42.503 = .246.

Table 6.5.

Tension added values derived from Regression when minor = 19.75

Factor	Level	Tension added
Inversion:	Root	0.643
	First	7.451
	Second	9.345
Melody:	Melody 1	5.741
	Melody 3	4.512
	Melody 5	3.947
Quality:	Major	0.246

To put these Regression values in perspective, let us turn to tension values from other parts of Lerdahl's model.[403] First, all tension added values due to surface dissonance, as determined by Ratio, are less than any other values Lerdahl calculates in other parts of his model. That is, features of chord formation, devoid of a tonal and musical context, create less tension than do relationships between chords within a tonal and musical context. For example, when all chords are in the same region, the least tension (5) perceived within a tonal and musical context is with the chord progressions I→V and I→IV (or any root movement of a fifth). The tension added values assigned by Ratio, to all levels of chord formations heard out of a tonal and musical context, are below this value of 5.

The tension added values determined by Regression equate these same chord progressions, heard within a tonal and musical context, with tension perceived out of a tonal and musical context due to Melody 1 (5.741) and due to Melody 3 (4.512). Regression also suggests First (7.451) and Second (9.345) Inversion, heard out of a tonal and musical context, are perceived as tenser than the chord progression with root movement of a fifth heard within a tonal and musical context, e.g., I→V and I→IV.

The most tense chord progression within a region occurs with root movement by seconds, i.e., I→ii and IV→V. Lerdahl's model predicts a perceived tension of 8 when heard within a tonal and musical context. The results of Regression suggest chords in Second Inversion (9.345), heard without a tonal and musical context, are perceived as tenser than root movement by second heard within a tonal and musical context.

In regional space, Lerdahl predicts a tension value of 10 when moving from the region of **I** to the region of **ii**, e.g., **A→b**. The highest predicted tension value (21), using Lerdahl's model, occurs when moving from the region of **I** to the region of ^{b}**iii**, e.g., **C→e**^{b}. Regression assigns tension due to minor Quality, heard without a tonal and musical context, a tension added value of 19.75. It seems unlikely listeners equate hearing a minor Quality chord heard without a tonal and musical context, with moving from the region of **I** to the region of ^{b}**iii** heard within a tonal and musical context. Thus, the tension added values obtained through Regression for levels of factors heard outside a tonal and musical context seem too high when compared with tension perceived for events within a tonal and musical context.

403 Keep in mind, Lerdahl's *Surface Tension Rule* suggests tension added values due to surface dissonance are outside of a tonal and musical context. The pitch space and inherited tension values are determined within a tonal and musical context.

Portion of Total Perceived Tension

A method similar to Ratio for determining new tension added values for Lerdahl's *Surface Tension Rule* is finding the Portion of the total perceived tension for which each variable is responsible. Table 6.6 lists the total of the means of medians perceived tension and corresponding Portion of total perceived tension by variable.

Table 6.6.

Portion of total perceived tension by variable level

Factor	Level	Total mean of medians	Portion
Inversion	Root	221.9512	.3
	First	253.2927	.34
	Second	263.5671	.36
Melody	1	269.6098	.36
	3	237.8841	.32
	5	231.2171	.31
Quality	Major	243.628	.33
	minor	495.1829	.67
Total		738.811	

Note. Portion = (level mean of medians perceived tension) / (total perceived tension).

Compared with Lerdahl's tension added values, Ranking, Ratio, and Regression, Portion returns the smallest (.3 to 1) range of tension added values. As a consequence of the smaller range, tension added values determined by Portion are closer together better representing the differences in effect sizes (chapters 3 and 4).

Intuition based on experience with Western tonal music suggests the values obtained through Ratio or Portion better represent our experience of perceived surface tension due to Inversion, Melody, and chord Quality than do those obtained by either Ranking or Regression. Perhaps revisiting the results of this study may aid in establishing which method—Ranking, Ratio, Portion, or Regression—best represents levels of perceived tension, allowing modification of Lerdahl's tension added values.

Seven Aspects of Lerdahl's Tension Added Values Requiring Modification

The first three findings to address are related and can be dealt with together.

1. *Tension added values for Root position and Melody 1 are not 0,*
2. *Tension added values for Root position and Melody 1 are not equal.*
3. *A tension added value is necessary for chord Quality.*

Lerdahl assigns a tension added value of 0 for both Root position and Melody 1. This study demonstrates participants perceived tension above 0 for both Root position and Melody 1. Furthermore, participants also perceived tension due to Major Quality chords, meaning a value of 0 (assumed as Lerdahl does not assign any tension added value for chord Quality) is not appropriate for this level either.

Table 6.7.

Summary of tension added values obtained through Ranking, Ratio, and Regression[404]

Factor	Level	Mean of medians	Rank	Ratio	Regression	Portion
Inversion	Root	36.99	2	1.37	0.643	.3
	First	42.22	4	1.56	7.451	.34
	Second	43.93	5	1.62	9.345	.36
Melody	1	44.93	5	1.66	5.741	.36
	3	39.65	3	1.46	4.512	.32
	5	38.55	3	1.42	3.947	.31
Quality	Major	27.07	1	1	0.246	.33
	minor	55.02	6	2.03	19.75	.67

From the summary of tension added values obtained through Ranking, Ratio, Regression, and Portion (Table 6.7), we can see all methods assign values greater than 0 for Root position, Melody 1, and Major chord Quality. Ranking assigns tension added values of 2 for Root, 5 for Melody 1, and 1 for Major Quality chords, suggesting tension due to Melody 1 is somewhat greater than that due to Root position, and much greater than that due to Major Quality. Ratio assigns 1.37, 1.66, and 1 respectively, suggesting Root position is a third again tenser than Major Quality, and Melody 1 half again as tense as is Major Quality. Regression assigns .643, 5.741, and .246 respectively, suggesting Root position is 3 times as tense as Major Quality and Melody 1 is 23 times as tense as Major Quality. Portion assigns .3, .36, and .33 respectively, suggesting the influence is small and relatively similar for Root position, Melody 1, and Major Quality chords. For the first three aspects, experience of Western tonal music and the results of this study (mean of medians) would lead us to choose new tension added values, and their relationships, established through Ratio or Portion rather than through Ranking or Regression.

All methods assign a higher tension added value to minor Quality chords than to Major Quality chords. Tension added due to minor chord Quality is twice that of tension due to Major chord Quality when determined by Ratio (2.03 and 1, respectively) and Portion (.67 and .33, respectively) but 80 times when determined by Regression (.246 and 19.75, respectively). I believe the values determined by Ratio and Portion are more in line with listeners' experience of chord Quality.

4. *Tension due to First Inversion is not the same as tension due to Second Inversion.*

Each of Ranking (First Inversion = 4, Second Inversion = 5), Ratio (1.56 and 1.62, respectively), Portion (.34 and .36, respectively), and Regression (7.451 and 9.345, respectively) follow this third directive. The relationship between the values produced by all methods seems to represent our experience of these chords in a musical and tonal context, and the results of this study. Second Inversion chords sound tenser than do First Inversion chords, when in or outside a musical and tonal context. Tension added values determined by Ranking and Regression, in the context of other values in Lerdahl's model, seem too large. Tension added values determined by Ratio and Portion better represent participant's experience of these chords.

[404] See Table J.5 in Appendix J for inclusion of values determined by Ratio to minor chord Quality.

5. *The tension added value for Melody 3 and Melody 5 are the same.*

Lerdahl's *Surface Tension Rule* assigns the same tension added value (1) for Melody 3 and Melody 5. Data from this study confirms the tension perceived when hearing Melody 3 and Melody 5 out of a musical and tonal context does not differ significantly. Ranking was adjusted to comply with this result, as both Melody 3 and Melody 5 were ranked third. Both Ratio and Regression assign Melody 3 a higher tension added value than that for Melody 5. Portion assigns Melody 3 a slightly higher value than Melody 5. Once again, Ratio (1.46 and 1.42) and Portion (.32 and .31) better reflect the data than does Regression (4.512 and 3.947).

6. *The tension added value due to First and Second Inversion should be larger than the tension added value assigned to Melody 3 and Melody 5.*

All approaches to assigning tension added values respect this directive. As before, the differences are larger when determined by Regression than when determined by Ranking, Ratio, and Portion.

7. *Tension perceived due to Second Inversion does not differ significantly from tension perceived due to Melody 1.*

Ranking was adjusted to reflect this result. The tension added values assigned by Ratio (1.62 and 1.66, respectively) are quite close, certainly much closer than are those assigned by Regression (9.345 and 5.741, respectively). Those assigned by Portion are equal (.36). Thus, Portion, and to a lesser degree, Ratio assign suitable tension added values.

The tension added values and their relationships to each other suggested by Ratio and Portion seem to be more representative of the data in this study. The values assigned to Second Inversion and Melody 1, as stated above, are an example of this. The values suggested by Regression and Ranking seem out of proportion with the other values Lerdahl assigns events within a tonal context. One would expect the forces acting within the tonal context to have more effect than those due to the formation of the chords and the resulting surface tension. Thus, adding the Regression value of 19.75 for the occurrence of a minor Quality chord seems unreasonable as does adding 6 as prescribed by Ranking, while adding the Ratio value of 2.03 or Portion's .67 seems fitting.

Surface Tension, Local Tension, and Global Tension[405]

Perhaps substituting tension added values suggested by Ratio, Regression, Portion, and Lerdahl's *Surface Tension Rule* (*STR*) into one of Lerdahl's pre-existing analyses will make clear the better choice for modifying tension added values for *STR*.[406]

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[405] This Figure is based on the prolongational reduction (Figure 4.5, p. 147) and hierarchical tension (Figure 4.11, p. 152) taken from Lerdahl (2001). Any diminished and seventh chords were changed, as they were not included in the stimuli used in this study. Thus, Event 4 was changed from vii^{o6} to V^6_4, Event 7 from V^4_2 to V^6_4, Event 9 from V^4_2 to V, Event 11 from ii^7 to ii^6, and Event 12 from V^7 to V. The changes to Lerdahl's original figure also resulted in several changes to the various melody lines and consecutive Perfect 5ths between the alto and soprano of events 10 and 11.

[406] The tension added values determined by Ranking are not included as, noted in the previous section, the values seem out of proportion with the other values Lerdahl assigns events within a tonal context. While the same could be said about tension added values determined by Regression, these values are included as they are the result of a more sophisticated statistical test and to demonstrate the effect of larger tension added values.

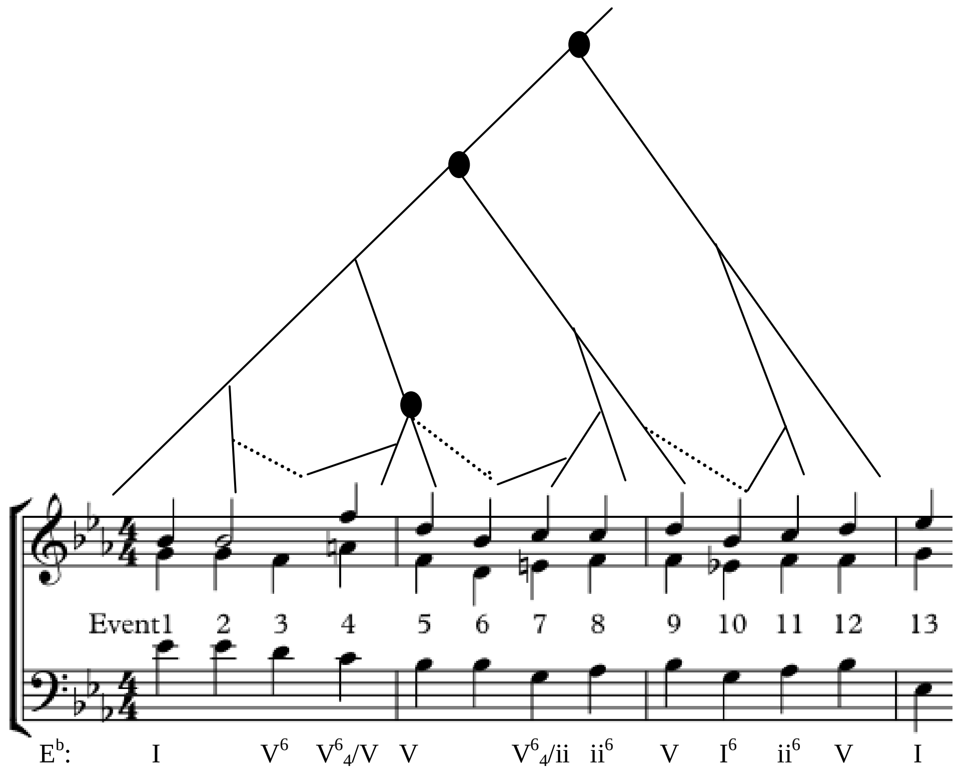

Figure 6.1. Modified Prolongational reduction and hierarchical tension taken from Lerdahl (2001), Figure 4.5, 147. Filled circles indicate weak prolongation. Dashed lines indicate sequential branching.

Surface tension

Figure 6.2 shows the total surface tension when calculated using Ratio, Regression, Portion, and *STR*.[407] Each method of calculating surface tension follows the same basic pattern. Regression has a greater range of values and steeper changes indicating greater differences in perceived tension than do Ratio, Portion, and *STR*. For the category of surface tension, Regression correlates better with *STR* [$r(11) = .76$, $p = .002$] than does Ratio [$r(11) = .70$, $p = .008$] or Portion [$r(11) = .66$, $p = .013$]. As we will see shortly, a stronger correlation with *STR* at this level is not necessarily a good thing. Because some of the values calculated by Regression are much larger than values calculated by Ratio, Portion, and by *STR*, Figure 6.3 is included, as it shows more detail for the total surface tension when calculated using Ratio, Portion, and *STR*.

Regression values for surface tension, at events 3, 4, 7, 8, 10, and 11, are much higher than are Ratio, Portion, and *STR* values for the same events. Events 3, 8, 10, and 11 are all First Inversion_Melody 5 chords. Regression, for First Inversion, adds a large value (7.451) while Ratio adds 1.56, Portion adds .34, and *STR* adds 2. Furthermore, Events 8 and 11 have higher values because they are minor Quality chords. Ratio adds 2.03 for minor Quality chords, Portion adds .67, *STR* adds 0, and Regression adds 19.75. Higher Regression values for events 4 and 7 are due mostly to Second Inversion with a smaller contribution due to Melody 1. The tension value added to

[407] See Appendix J, Tables J.1 to J.4 for values used to calculate tension for surface tension, local tension, and global tension for each event.

Second Inversion, for Ratio, is 1.62, .36 for Portion, 2 for *STR*, and 9.345 for Regression. The tension value added to Melody 1, for Ratio, is 1.66, .36 for Portion, 1 for *STR*, and 5.741 for Regression.

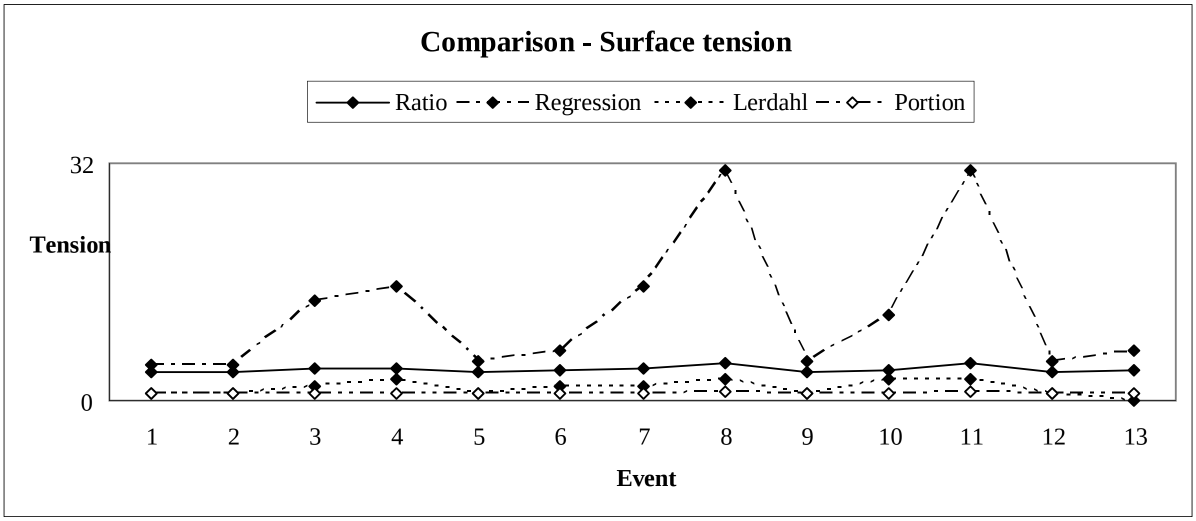

Figure 6.2. Values for Surface tension (Inversion, Melody, and chord Quality) by event, as determined by Ratio, *Regression*, Lerdahl's *Surface Tension Rule*, and Portion.

Evident in Figure 6.3 are the lower tension added values determined by Portion. Not only are the values lower than those obtained by Ratio or *STR*, but the range is smaller. The result is less fluctuation in tension due to Inversion, Melody, and chord Quality. The importance of this will become clear in the discussion of Figures 6.6 to 6.9.

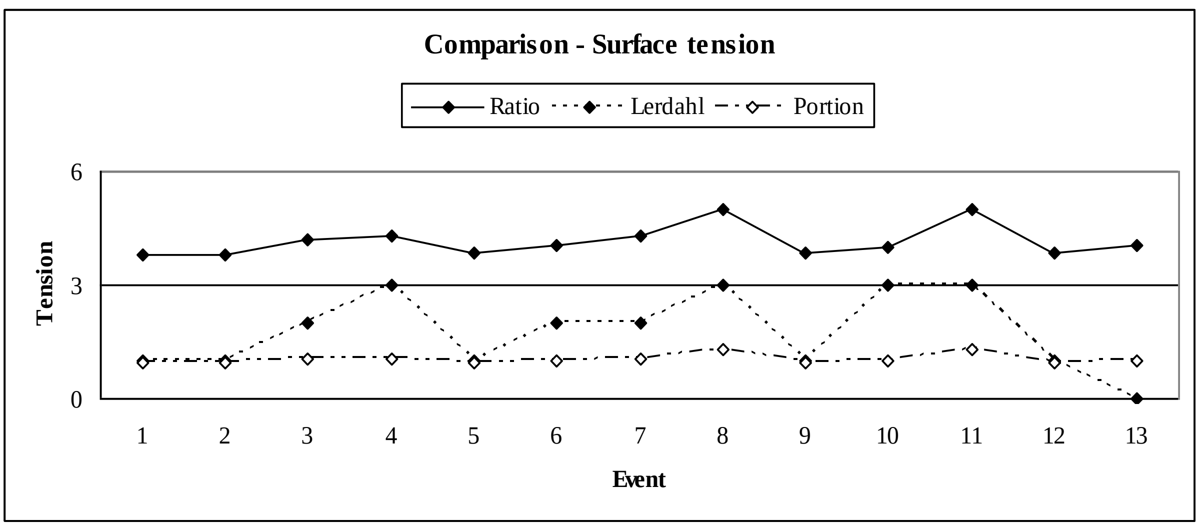

Figure 6.3. Values for Surface tension (Inversion, Melody, and chord Quality) by event, as determined by Ratio, Lerdahl's *Surface Tension Rule*, and Portion. [408]

[408] See Figure J.2 in Appendix J for comparison between surface tension using tension added values calculated using Ratio to minor chord Quality and Portion.

Local tension

In Figure 6.4 are the values for local tension (surface tension—Ratio, Regression, Portion, and *STR*—plus tension due to pitch space distances) for each event in Figure 6.1. Once again, the values for Regression are higher and the changes steeper than are those for Ratio, Portion, and *STR*, indicating greater change in perceived tension between events. Also once again, the general shape is the same each method. Unlike values for surface tension, Ratio [$r(11) = .97$, $p = .00001$] and Portion [$r(11) = .97$, $p = .00001$] , values for local tension, correlate better with *STR* than does Regression [$r(11) = .81$, $p = .0003$].

One of the reasons Regression correlates less strongly at the level of local tension may be due to events 9 and 10. When moving from event 9 to event 10, Ratio, Portion, and *STR* predict listeners will experience a reduction in local tension, while Regression predicts listeners will experience an increase in local tension. Event 9 is Root_Melody 3_Major Quality and event 10 is First Inversion_Melody 5_Major Quality. Lerdahl adds 0 to event 9 for Root position and 2 to event 10 for First Inversion. He adds 1 to both events for Melody 3 and Melody 5. Based on the results of this study, Ratio, Portion, and Regression add a small value for Root position and a larger value for First Inversion. Ratio, Portion, and Regression also add a larger value for Melody 3 than for Melody 5. The difference between Regression added tension for Root position and for First Inversion is much larger (6.81) than the same comparison for Ratio (.19), Portion (.04), and *STR* (2). However, the difference between Regression added tension for Melody 3 and for Melody 5 is not much different (-.56) than the difference for Ratio (-.04), Portion (-.01), and *STR* (0). Because of the large tension added value for First Inversion, Regression shows an overall increased local tension when moving from event 9 to event 10 while Ratio, Portion, and *STR*, with their smaller tension added values, show an overall decrease in local tension.[409]

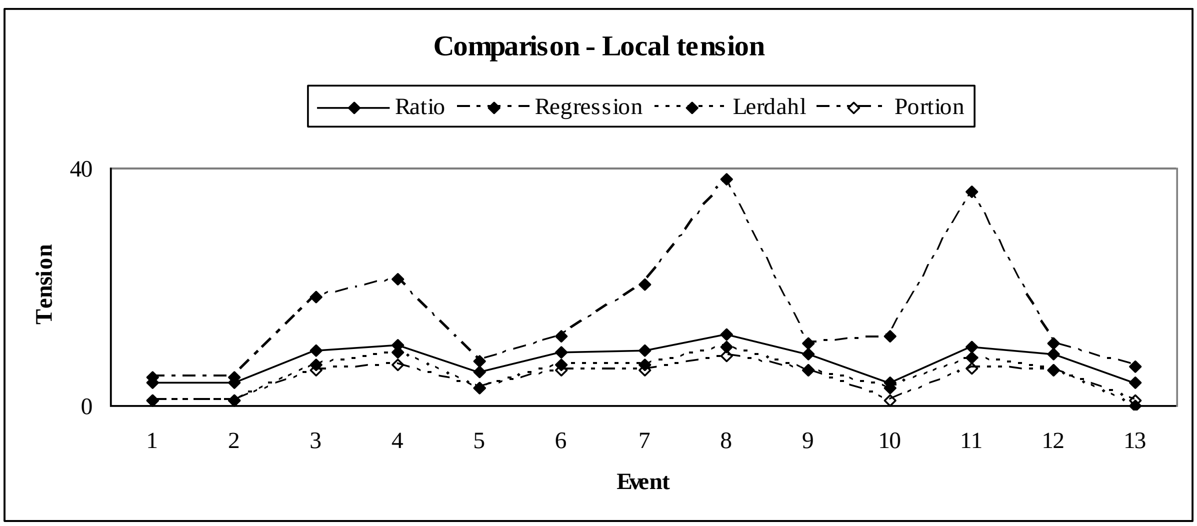

Figure 6.4. Values for Local tension (Surface tension plus Regional, Chordal, Pitch class spaces) by event, as determined by Ratio, Regression, Lerdahl's *Surface Tension Rule*, and Portion.[410]

[409] Total perceived tension, due to surface tension, for Regression = -.56 + 6.81 = 6.25; for Ratio = - .04 + .19 = .15; for Portion = .04 - .01 =.03; for *STR* = 2 + 0 = 2.

[410] See Figure J.3. in Appendix J for local tension due to surface tension for Ratio to minor chord Quality and Portion.

Global tension

The ultimate goal of Lerdahl's predictive model of tonal tension is global tension (Figure 6.5). Tension due to surface dissonance, movement through regional, chordal, and pitch class spaces, and tension inherited by subordinate events from superordinate events are summed. Lerdahl argues global tension represents the experience of listeners familiar with Western tonal music.[411] As with surface tension and local tension, Regression has higher tension values than Ratio, Portion, and *STR*, but all methods continue to have the same basic shape. As with local tension, global tension values for Ratio [$r(11) = .99$, $p = .00001$] and Portion [$r(11) = .99$, $p = .00001$] correlate better with *STR* than does Regression [$r(11) = .89$, $p = .00001$].

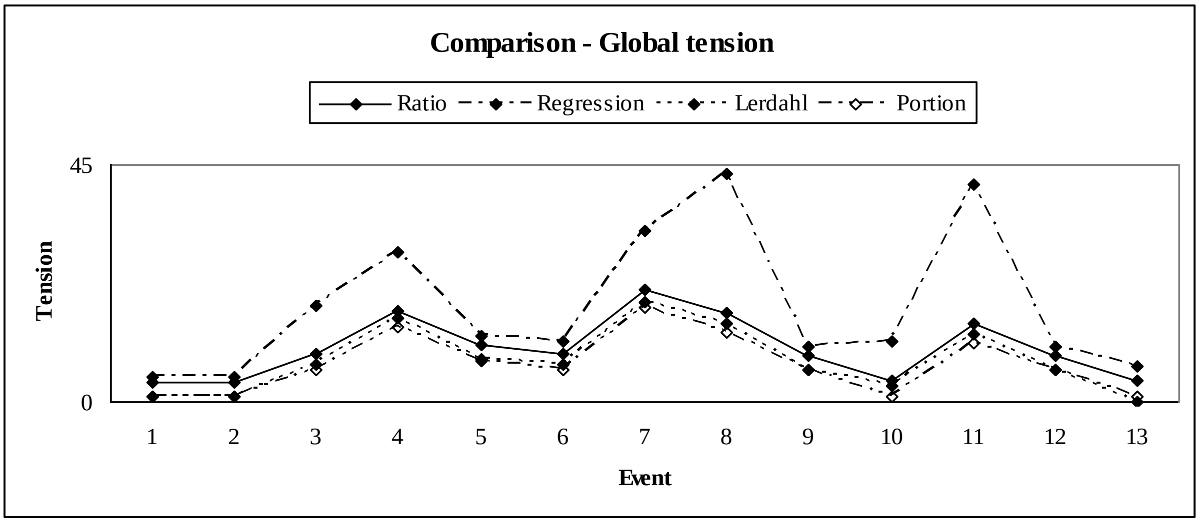

Figure 6.5. Values for Global tension (Surface tension plus Regional, Chordal, Pitch class spaces plus inherited tension) by event, as determined by Ratio, Regression, Lerdahl's *Surface Tension Rule*, and Portion.[412]

Influence of Surface Dissonance on Global Tension

Global tension is the sum of tension due to surface dissonance, pitch space distance, and inherited tension. Lerdahl believes global tension predicts tension perceived by experienced listeners. The tension due to pitch space (regional, chordal, and pitch class) and inherited are the same regardless of method used to determine surface tension. Thus, we can ascertain the influence on global tension associated with surface features, pitch space, and inherited. Figures 6.6 to 6.9 show tension due to surface dissonance, as determined by Lerdahl's *Surface Tension Rule*, Ratio, Regression, and Portion, compared with global tension.

In Figures 6.6 to 6.9, we can see, regardless of the method used to modify Lerdahl's tension added values, surface tension is equal to global tension for events 1, 2, 10, and 13. The chords at these events are all versions of I/**E**$^{\mathbf{b}}$. As events 2, 10, and 13 are linked hierarchically to event I there is no tension due to pitch space. The chords have not changed region, chordal space, or pitch class space. Because they inherit 0 from event 1, surface tension is equal to global tension for these events. Stated another way, surface tension is the primary source of perceived tension for prolongation.

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[411] Lerdahl believes listeners with less experience of Western tonal music hear sequentially rather than hierarchically.
[412] See Figure J.4 and J.6 in Appendix J for values for Global tension determined by Ratio to minor chord Quality and Portion.

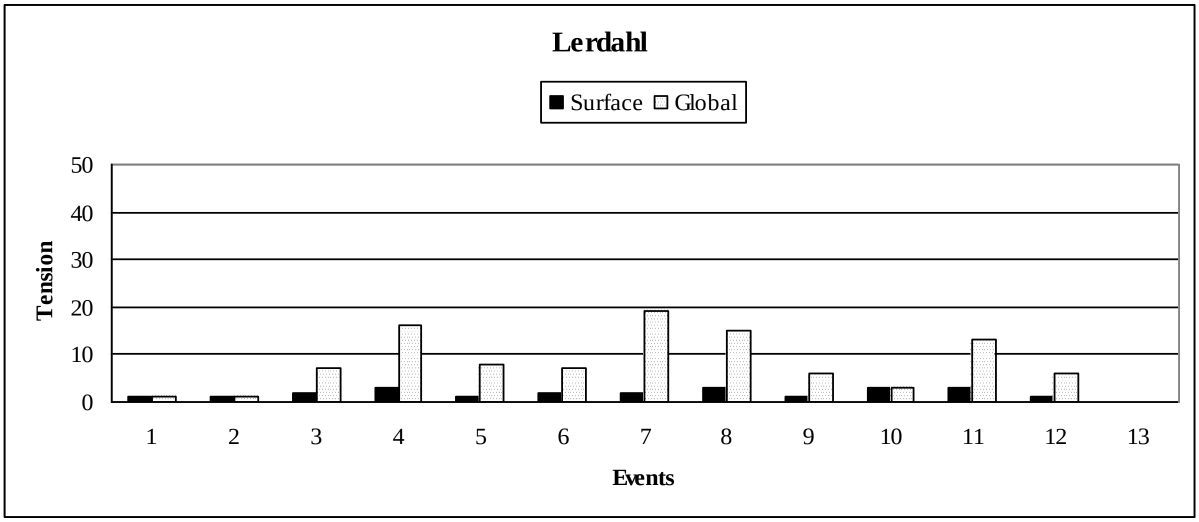

Figure 6.6. Surface and global tension calculated using values suggested by Lerdahl's model. Note. There are no columns for event 13 because both surface and global tension values are 0.

Using tension added values from *STR*, Figure 6.6 shows a mildly fluctuating contribution (0 to 3) of surface tension to global tension. With Ratio (Figure 6.7), surface tension is a more consistent contributor (3.79 to 5.01) to global tension. As noted previously, Regression values for surface tension (4.84 to 31.15) are responsible for a large part of global tension (Figure 6.8). Weighting of Inversion, Melody, and chord Quality by Portion (Figure 6.9) adds little to the global tension (.3 to .67). That is, surface tension is not the primary source of perceived tension for progression when using the tension added values determined by Portion.

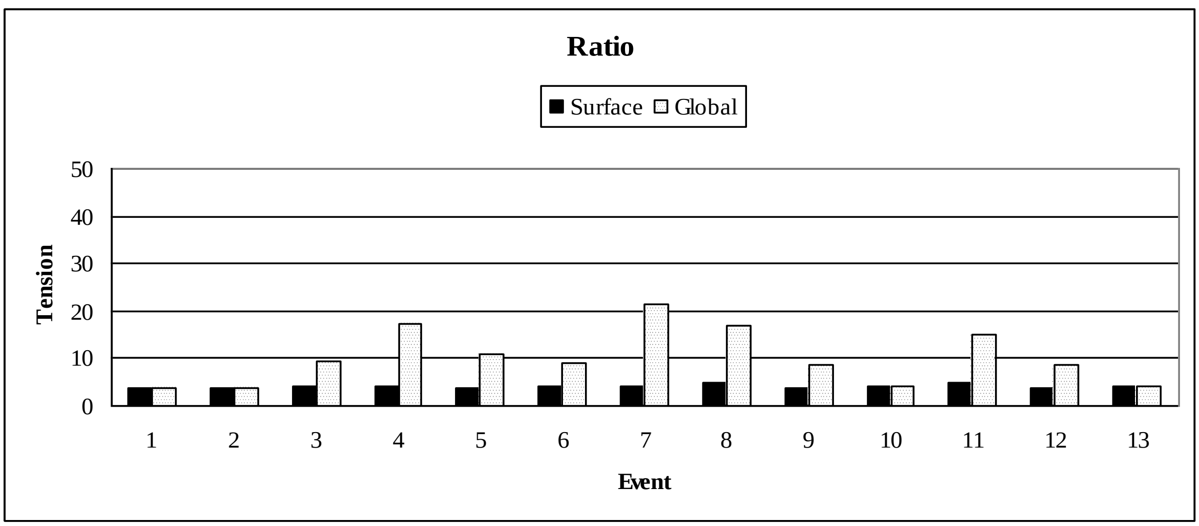

Figure 6.7. Surface and global tension calculated using values suggested by Lerdahl's model using Ratio tension added values instead of those suggested by *STR*.[413]

As stated above, regardless of method, surface tension equals global tension for events 1, 2, 10, and 13. In the case of an application of Lerdahl's model (Figure 6.6), Ratio (Figure 6.7), and Portion (Figure 6.9), surface

[413] See Figure J.5 in Appendix J for surface and global tension calculated using Ratio to minor.

tension plays a lesser role in the remaining events. This is not true for Regression (Figure 6.8) where surface tension is a significant contributor to global tension.

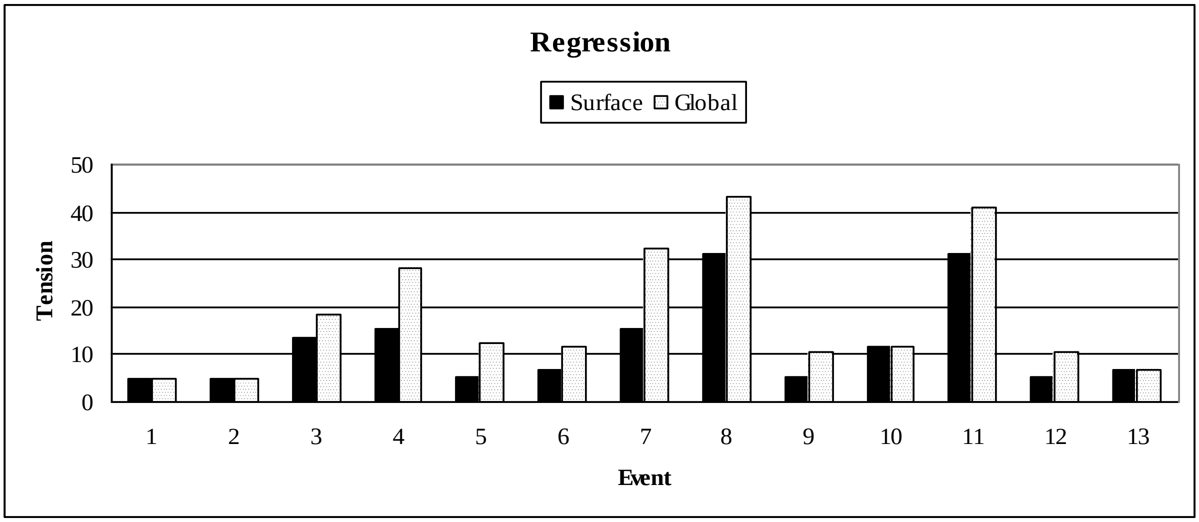

Figure 6.8. Surface and global tension calculated using values suggested by Lerdahl's model using Regression tension added values instead of those suggested by *STR*.

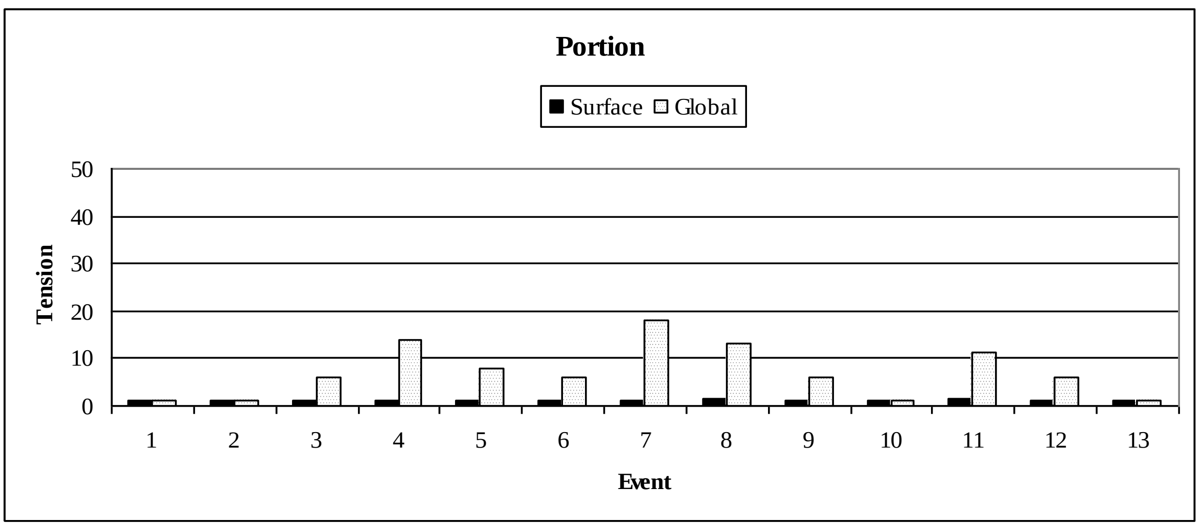

Figure 6.9. Surface and global tension calculated using values suggested by Lerdahl's model using Portion tension added values instead of those suggested by *STR*.

Table 6.8 identifies which component of Lerdahl's model—surface tension, pitch space, or inherited—contributes most to global tension, the level of tension perceived by listeners experienced with Western tonal music. Using the values determined by Lerdahl's *Surface Tension Rule* (Table G.3 and Figures 6.5 and 6.6), the values determined by substituting surface tension values calculated by Ratio (Table G.2 and Figures 6.5 and 6.7), and those determined by Portion (Table G.4 and Figures 6.5 and 6.9), we see surface tension is the determining factor when the other components have a value of 0.

The exception is event 11. For Lerdahl's model, surface tension (3), pitch space (4), and inherited (5) are close in value. Even here, surface tension contributes the least tension. We find a similar result at event 11 when

Ratio is used to calculate surface tension. The contribution of surface tension (5.01) is equal to the contribution of pitch space (5) and of inherited tension (5).

For 10 of 13 events, surface tension values determined by Regression contribute the most to global tension. Surface tension determined by Regression—like Lerdahl's model, Ratio, and Portion—is the only contributor to global tension for events 1, 2, 10, and 13. Regression surface tension values and pitch space distance contribute similar values for events 6 (6.63, 5), 9 (5.4, 5), and 12 (5.4, 5). Regression surface tension values contribute a large amount to global tension for events 4 and 8. Event 4 is a Second Inversion_Melody 1_Major. Both Second Inversion and Melody 1 have large tension added values (totalling 15.33) when compared to the values for pitch space (6) and inherited (7). The same is true for the Second Inversion_Melody 5_minor chord at event 8 (surface tension = 31.15, pitch space = 7, inherited = 5).

Table 6.8.

Summary of which component of Lerdahl's model—Surface tension, Pitch space, Inherited tension—contribute most to global tension

Event	Surface tension	Pitch space	Inherited tension
1	L, Ra, Re, P	0	0
2	L, Ra, Re, P	0	0
3		L, Ra, Re, P	0
4	Re		L, Ra, P
5			L, Ra, Re, P
6	Re	L, Ra, Re, P	0
7			L, Re, Ra, P
8	Re	L, Ra, P	
9	Re	L, Ra, Re, P	0
10	L, Ra, Re, P	0	0
11		L, Ra, Re, P	L, Ra, Re, P
12	Re	L, Ra, Re, P	0
13	L, Ra, Re, P	0	0

Note. L = Lerdahl's model, Ra = new surface tension values derived by Ratio, Re = new surface tension values derived by Regression, 0 = no contribution, P = new surface tension values derived by Portion.

Ranking, Ratio, Regression, and Portion are methods that can be applied to the data from this study to modify Lerdahl's tension added values due to surface dissonance. In his *Surface Tension Rule*, Lerdahl employed a limited range (0 to 2) of Ranking values for Inversion and Melody, and included no value for tension due to chord Quality. To represent the results of this study, Ranking was modified to 6 levels of perceived tension that included levels of Inversion, Melody, and chord Quality. Regression provided the greatest range of values while Ratio and Portion provided a smaller range of values. Which method provides the values which best represent the relationships among the levels of the 3 within subjects factors? Which method provides the values which best represent the listeners' experience of tension due to chord formations heard outside of a musical and tonal context? Before addressing these questions leading to the modification of Lerdahl's tension added values due to surface tension, I would like to discuss the role of Expertise in this study.

Expertise[414]

Because Western tonal music is pervasive in the environment from which participants for this study were drawn, it is difficult to quantify Expertise in tonal music. There has been a tendency to categorise participants solely on explicit knowledge i.e., their achieved level of music education. At the same time, implicit knowledge gained through listening experience is known to influence listeners' perception.

Expertise played a role in Krumhansl's probe tone studies (chapter 2). The best results were obtained from participants with what she describes as a moderate level of musical experience. This means "participants have studied an instrument or instruments for five to fifteen years, have participated in performing groups for a number of years, and spend quite a bit of time listening to music. The choice of this subject population was based on a desire to obtain fairly precise and reliable data about implicit knowledge of musical structure gained through experience with music, rather than through explicit instruction in music theory."[415]

Lerdahl refrains from explicitly defining Expertise other than to say, like *A Generative Theory of Tonal Music*, his model predicting perceived tension in Western tonal music "assumes an 'experienced listener'."[416] This study shows listeners, across a wide range of Expertise of Western tonal music, perceive surface tension in four-note chords—varying in Inversion, Melody, and chord Quality, and heard in the absence of a tonal and musical context—in a similar manner. This result suggests the effect of experience in Western tonal music is not the sole contributing factor to listeners' perception of tension due to Inversion, Melody, and chord Quality heard outside a musical and tonal context. The results suggest the acoustic signal has some effect upon perception of tension, an effect not uncovered by roughness values of Vassilakis and Fitz's *Spectral and Roughness Analysis* or the instability values of Cook's *Seeing Harmony* (chapter 5), but perhaps by Lahdelma and Eerola's sharpness variable.

Conclusions

Lerdahl asserts the *Surface Tension Rule* "evaluates the psychoacoustic tension caused by surface features of an event. The sensory dissonance of an event is affected by which pitches are in the bass and which in the soprano."[417] This statement suggests the structure of the chord and its acoustical properties, devoid of a musical and tonal context, affect listeners' perception of tension in Western tonal music. Certainly, the tenets of music theory support this assertion (see Chapters 1 and 3).[418] Yet, as we discovered when analysing the stimuli, for roughness using Vassilakis and Fitz's *Spectral and Roughness Analysis,* and for instability using Cook's *Seeing Harmony*, the interaction of chord tones and their partials cannot explain the results of this study (see Chapter 5). Lahdelma and Eerola suggest roughness is but one characteristic of sound contributing to the perception of tension in chords heard

[414] See Appendix K for further discussion on defining musical expertise.
[415] Carol Krumhansl, "Perceptual Structures for Tonal Music," *Music Perception* 1, no. 1 (1983): 35.
[416] Lerdahl (2001), 5.
[417] Lerdahl (2001), 150.
[418] It should be noted the rules of harmony and melody espoused by music theory relate to chords in a musical and tonal context.

outside a musical and tonal context. Roughness combined with sharpness and register may explain listeners' perception of chords heard in isolation.

With respect to his categories of surface tension, Lerdahl states, "[t]hese numerical values are first approximations pending empirical feedback."[419] Lerdahl's values for Inversion and Melody used to determine surface tension do not reflect the results of this study. Furthermore, this study shows it is necessary to add a new category of surface tension, chord Quality.

The revised version of Ranking has more levels of tension (6) to those proposed by Lerdahl (3). This has limited usefulness, however. Ranking does demonstrate lower, higher, and equivalent perceived tension. Ranking provides a position within a scale but does not offer clear relational information. Perhaps more importantly, the values obtained do not fit within the context of distances perceived in pitch space. Revised Ranking values give too much weighting to tension due to surface dissonance, overshadowing tension due to distances in pitch space and inherited tension. Ranking is not the best method to modify Lerdahl's tension added values from his *Surface Tension Rule*.

A large range of unsatisfactory values is the consequence of using Regression to modify Lerdahl's tension added values. The values determined by Regression are unsatisfactory because the result is a disproportionate contribution of surface tension to progression, both sequential and hierarchical. In addition, Regression does not equate tension due to Second Inversion with that due to Melody 1, in accordance with the results of this study. Also, Regression does not given equal tension added values for Melody 3 and Melody 5. Thus, Regression is not the best method to modify Lerdahl's tension added values due to surface dissonance.

Ratio and Portion, of the methods used to modify Lerdahl's tension added values for Inversion and Melody, and assign tension added values for the new category of chord Quality, arrive at numbers that both reflect the results of this study and assign weightings that do not overshadow the contributions of pitch space and inherited tension. I believe of the two (Ratio and Portion), Portion is the best method to determine the new tension added values for the levels of Inversion, Melody, and chord Quality shown to be necessary by the results of this study.

The contribution to global tension, as determined by Portion tension added values, better reflects the effect of chord formation within the context of tension due to hierarchical relationships established in Western tonal music. While the tension added values determined by Ratio are small, I believe they are too large in the context of the values Lerdahl assigns other factors like, for example, steps through chordal and regional space. Also, the tension added values determined by Ratio are likely too large in the context of other features which may contribute more to surface tension than levels of Inversion, Melody, Major and minor chord Quality. For example, the range of tension added values determined by Ratio is 1.37 to 2.03. The range determined by Portion is .3 to .67. The tension added due to diminished chords, nonchord tones, and added sevenths is likely to be more than tension added due to Inversion, Melody, and Major and minor chord Quality. Obtaining data for the remaining contributors to surface tension as outlined in Lerdahl's *Surface Tension Rule* is an important next step. It is likely new weightings for these tension added values could be assigned also using Portion.

[419] Lerdahl (2001), 150.

The results of this study indicate chord Quality has a larger effect upon listeners' perception of tension than do Inversion and Melody. When heard out of musical and tonal context, the tension perceived due to minor Quality chord is twice that of tension perceived due to Major chord Quality.[420] This result seems reasonable. Does it seem reasonable, however, to assign minor Quality chords a tension added value of 2.03 (Ratio) when Second Inversion is assigned 1.62? Portion assigns .67 for minor Quality chords and .36 for Second Inversion. I believe, when heard in a musical and tonal context, Second Inversion will be perceived as tenser than a minor Quality chord. The contribution of surface tension as determined by Ratio may overshadow the effect of chord relationships in a musical and tonal context. This is unlikely to happen with the smaller tension added values determined by Portion.

Does it seem reasonable to assign, as Ratio does, Melody 1 a value of 1.66, greater than that assigned to Melody 3 and Melody 5? Portion also assigns Melody 1 (.36) a larger value than either Melody 3 (.32) or Melody 5 (.31). I believe, when heard in a musical and tonal context, Melody 1 will be perceived as less tense than both Melody 3 and Melody 5. Once again, the contribution of surface tension as determined by Ratio may overshadow the effect of relationships active in a musical and tonal context. This is unlikely to happen with the smaller tension added values determined by Portion.

These questions support the use of smaller tension added values for Inversion, Melody, and chord Quality like those determined by Portion. Smaller values allow for a smaller effect of surface tension (derived from chords devoid of tonal and musical context) and a greater effect of perceived distance in pitch space and inherited tension (derived from chords within a tonal and musical context).

Lerdahl maintains surface tension depends upon the psychoacoustic properties of the chords and not their musical context. Yet, Vassilakis and Fitz's *Spectral and Roughness Analysis* and Cook's *Seeing Harmony*, cannot explain the results of this study. As Vassilakis said, "[t]he results [of *SRA*], therefore, indicate that roughness constitutes a significant but [*sic*] not the sole factor guiding listeners in their dissonance judgments."[421] It would seem listeners familiar with Western tonal music use chord Quality above all other factors (e.g., roughness, instability, tenets of music theory) to rate tension perceived when hearing four-note Major and minor chords outside a musical and tonal context.

The tension added values, determined by Portion, for the stimuli used in this study address the errors in Lerdahl's original values without overshadowing the other factors that 'guiding listeners.' While some of these new values are surprising, they do not overwhelm the contextual elements of Lerdahl's sequential and hierarchical tension. Rather, the new values determined by Portion reflect the results of this study and seem appropriately weighted within the context of the complete model.

While this study suggests modifications to Lerdahl’s model of tonal pitch space to better reflect listeners’ experience of Western tonal music, there remains more that should be tested empirically. Data should be obtained for tension added values due to diminished and augmented chord Quality, nonchord tones, and chords with added sevenths. The results of this study and discussion of the contribution of psychoacoustics characteristics of tetrachords heard out of a musical and tonal context show the psychoacoustic dimension also requires more investigation.

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[420] Accordingly, the tension added values obtained through Portion, perceived tension due to minor chord Quality (.67) is twice all levels of the three within subjects factors except for Second Inversion (.36) and Melody 1 (.36).
[421] Vassilakis (2001), 136.

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APPENDIX A: MUSICAL EXAMPLES OF LERDAHL'S FOUR HIERARCHIES

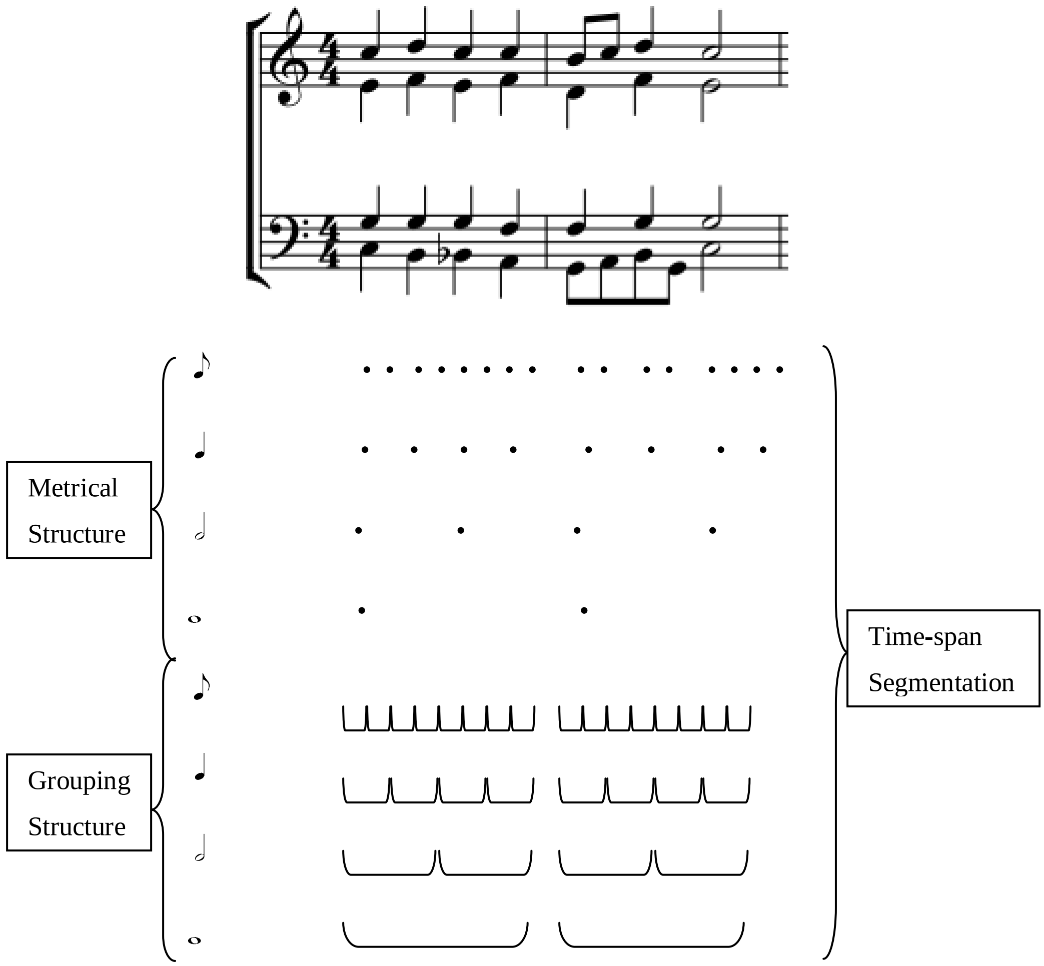

Figure A.1. Metrical and Grouping Structures combine to create Time-span Segmentation.

Figure A.2. Time-span Reduction.

Figure A.3. Prolongational Reduction.

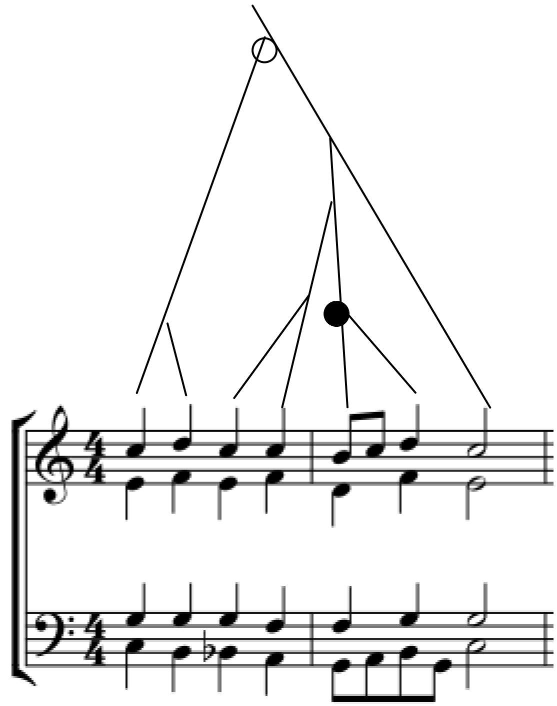

Figure A.4. Prolongational Reduction as Hierarchical branchings.

APPENDIX B: CHORD FORMATIONS AND ASSOCIATED DISRUPTOR SEQUENCES, PLUS CHORD FORMATIONS IN ALL MAJOR AND MINOR KEYS

Figure B.1. Disruptor sequences and chord formations for Major chord Quality, where Inversion: R = Root position, F = First Inversion, S = Second Inversion; Melody: 1 = Root of chord in top voice, 3 = Third of chord in top voice, 5 = Fifth of chord in top voice; Quality: M = Major, n = minor; s = seconds. Note. In the context of the study, there were no rests between the presentation of Disruptor Sequences and the Target chords.

Figure B.2. Disruptor sequences and chord formations for minor chord Quality, where Inversion: R = Root position, F = First Inversion, S = Second Inversion; Melody: 1 = Root of chord in top voice, 3 = Third of chord in top voice, 5 = Fifth of chord in top voice; Quality: M = Major, n = minor; s = seconds. Note. In the context of the study, there were no rests between the presentation of Disruptor Sequences and the Target chords.

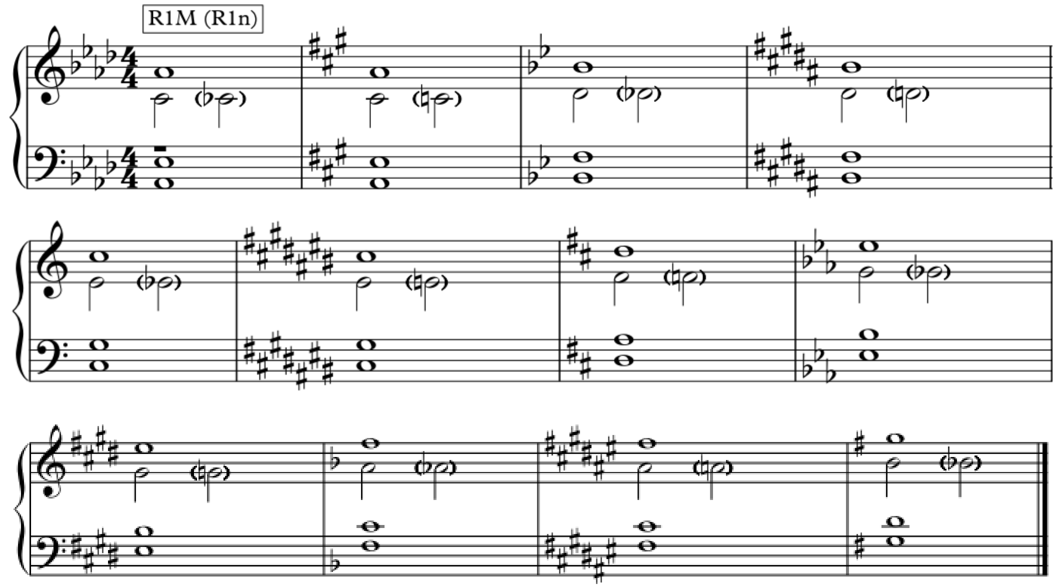

Figure B.3. Chord formations of R1M and R1n for all keys, where R = Root position, 1 = Root of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

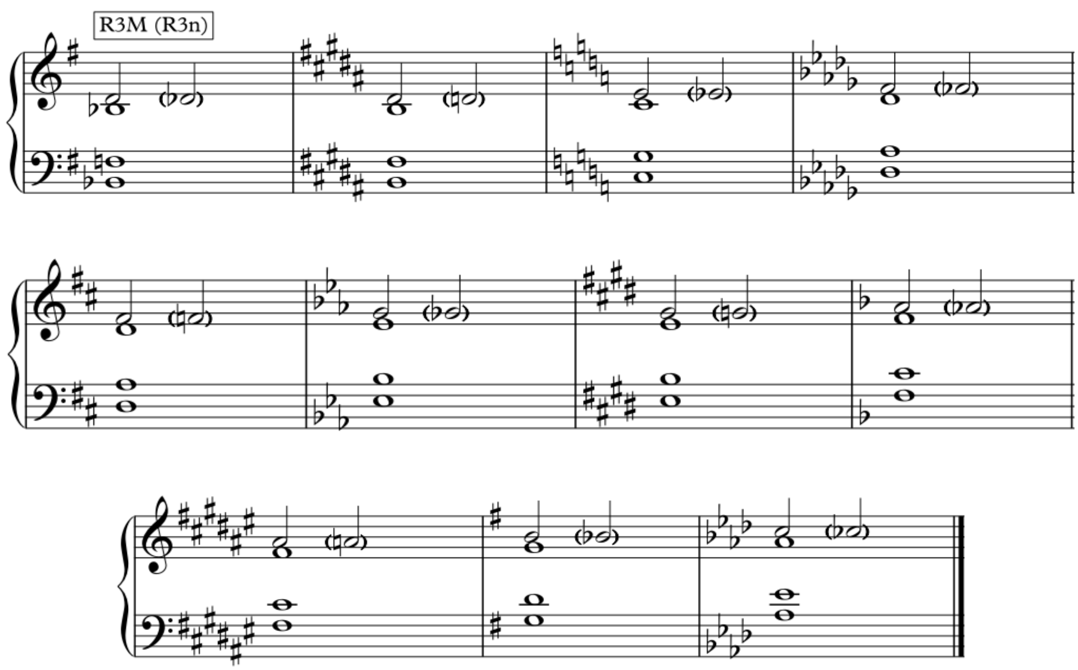

Figure B.4. Chord formations of R3M and R3n for all keys, where R = Root position, 3 = third of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

Figure B.5. Chord formations of R5M and R5n for all keys, where R = Root position, 5 = fifth of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

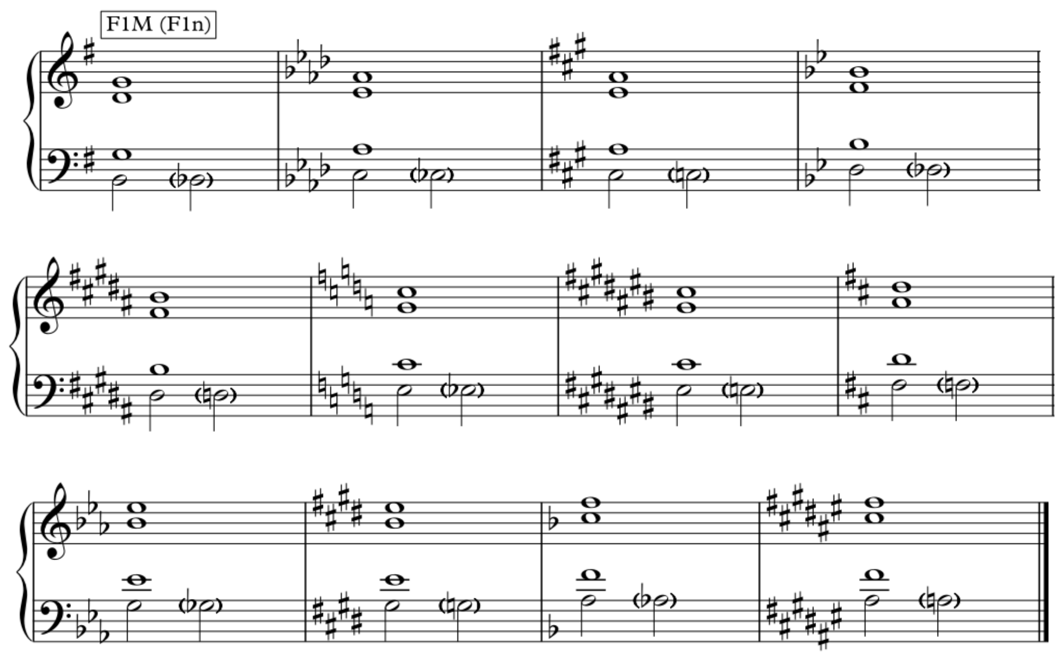

Figure B.6. Chord formations of F1M and F1n for all keys, where F = First Inversion, 1 = root of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

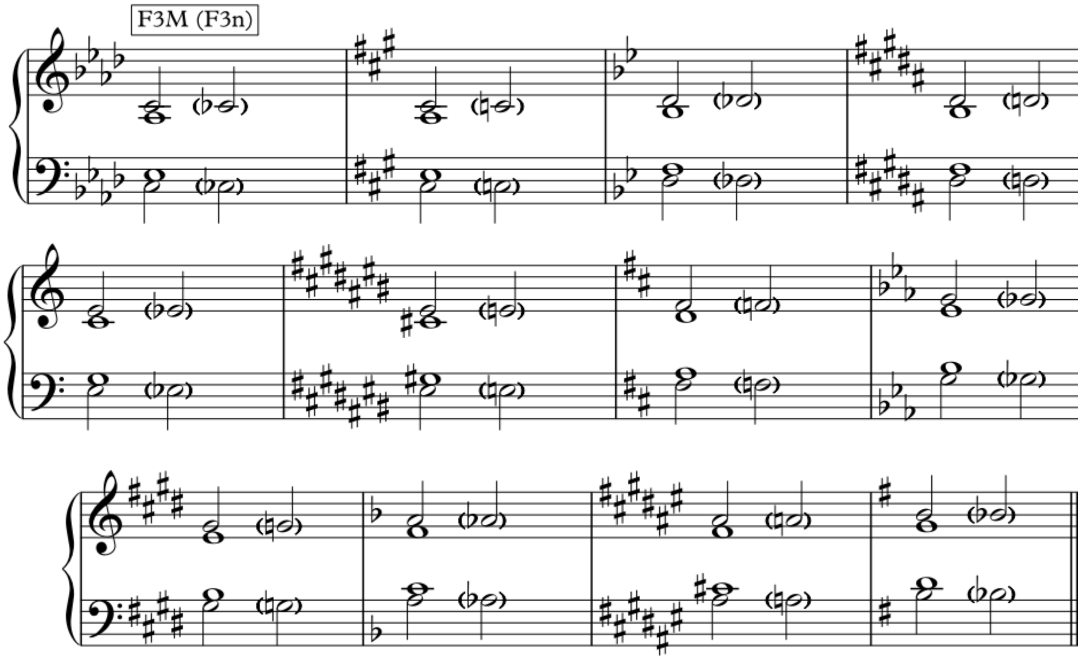

Figure B.7. Chord formations of F3M and F3n for all keys, where F = First Inversion, 3 = third of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

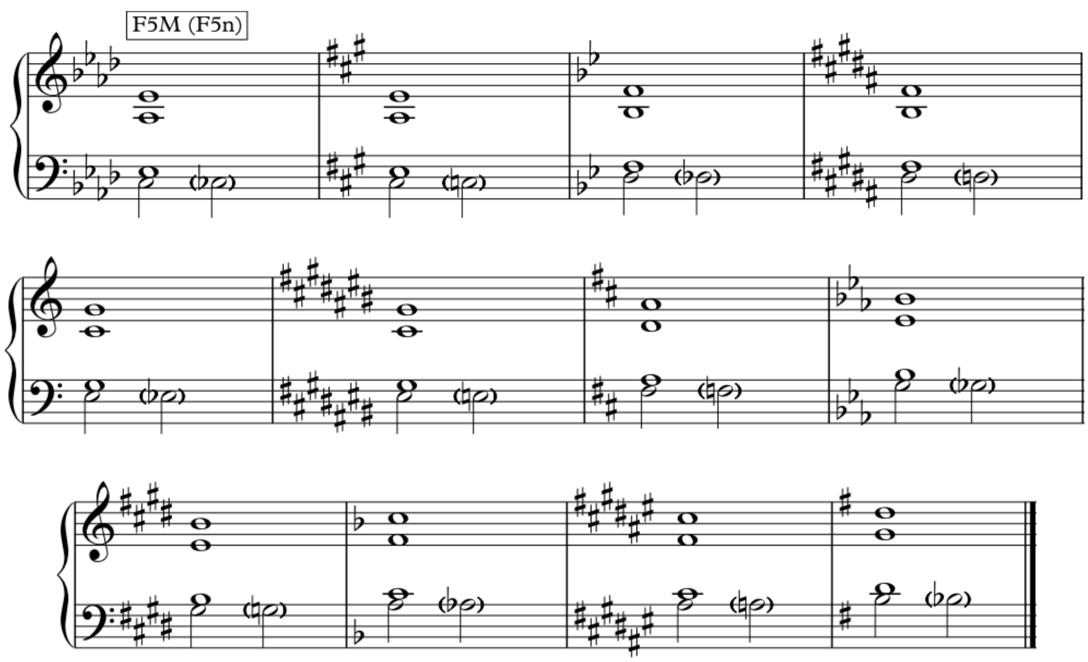

Figure B.8. Chord formations of F5M and F5n for all keys, where F = First Inversion, 5 = fifth of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

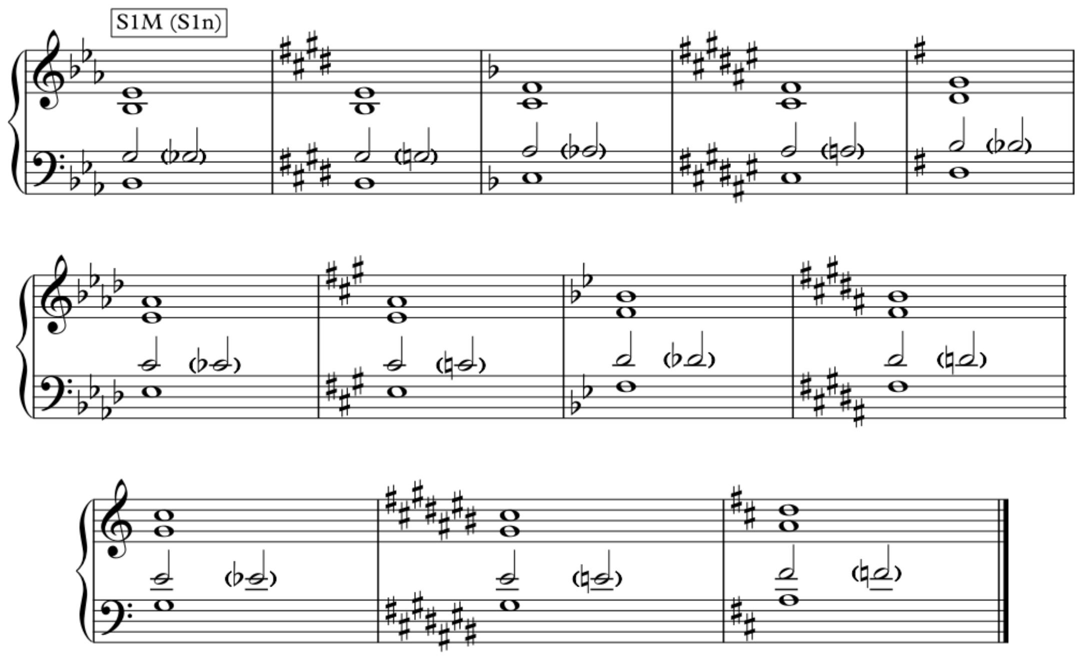

Figure B.9. Chord formations of S1M and S1n for all keys, where S = Second Inversion, 1 = root of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

Figure B.10. Chord formations of S3M and S3n for all keys, where S = Second Inversion, 3 = third of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

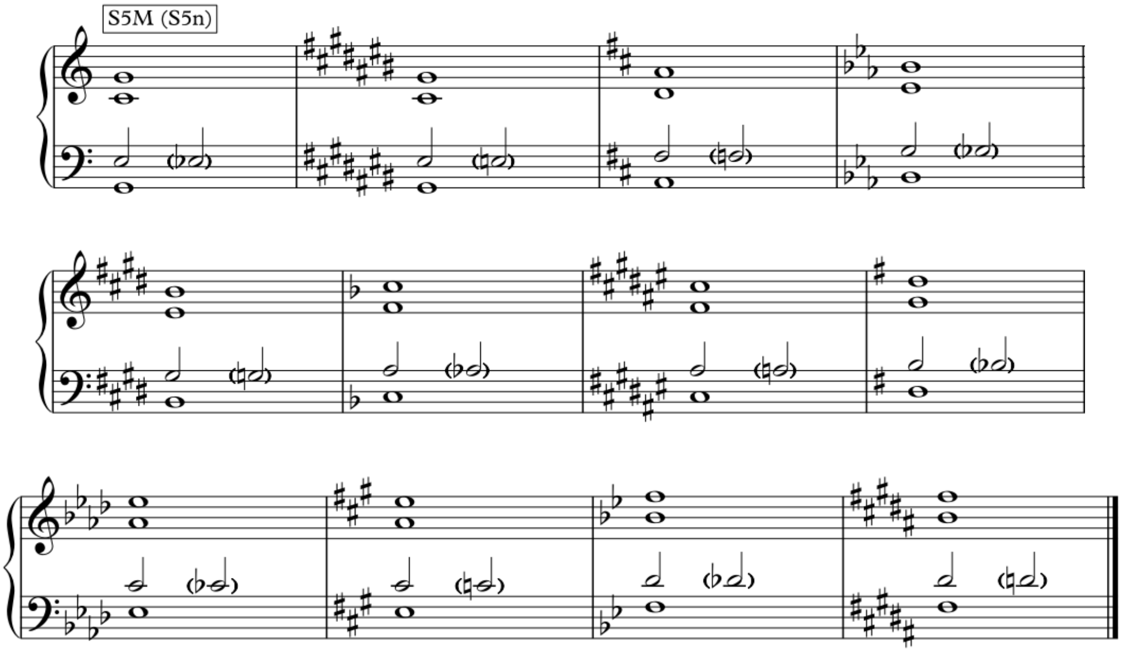

Figure B.11. Chord formations of S5M and S5n for all keys, where S = Second Inversion, 5 = fifth of chord in top voice, M=Major, and n = minor. Major chord formations are comprised of 3 whole notes and the unbracketed half note. Minor chord formations are comprised of 3 whole notes and bracketed half note.

APPENDIX C: EXPLANATION OF RANDOMISATION PROCESS

Participants heard 216 target chords in 3 different Inversions (Root, First, and Second) with 3 different Melody notes (1 = root of chord in the top voice, 3 = third of chord in top voice, and 5 = fifth of chord in top voice) and 2 chord Qualities (Major and minor). The 216 chords were divided into 6 blocks of 36 chords. All blocks were comprised of Major and minor Quality chords rooted on all 12 chromatic notes within the octave (see Table C.1). The chords within each block did not change from participant to participant (see Table C.2). However, the order in which the chords were presented in each block did change for each participant (see Table C.3). Similarly, all participants were presented with all six blocks of chords. However, the presentation order for the blocks of chords was also altered. The block order for 14 participants of Group I was 1, 2, 3, 4, 5, & 6; 2, 3, 4, 5, 6, & 1 for the 14 participants of Group II; 3, 4, 5, 6, 1, & 2 for another 14 participants of Group III; 4, 5, 6, 1, 2, & 3 for 13 participants of Group IV; 5, 6, 1, 2, 3, & 4 for 14 participants of Group V; and 6, 1, 2, 3, 4, & 5 for another 13 participants of Group VI; 82 participants in total.

Table C.4 summarises the distribution of the 36 chords in each block by Quality, Inversion, and Melody. In other words, Table C.4 shows, of the 36 chords in a particular block, how many were Major and how many were minor; of the 36 chords in the block, how many were Root position, how many were First Inversion, and how many were Second Inversion; of the 36 chords in the block, how many were Melody 1, how many were Melody 3, and how many were Melody 5.

Table C.1.

36 chords in blocks 1-6 ordered chromatically

Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Af_F_5	af_F_3	Af_F_1	Af_F_3	af_F_1	af_F_5
af_R_5	Af_R_1	Af_R_3	Af_R_5	af_R_3	af_R_1
Af_S_5	af_S_3	Af_S_3	af_S_5	af_S_1	Af_S_1
a_F_1	A_F_1	A_F_5	A_F_3	a_F_3	a_F_5
a_R_1	A_R_3	A_R_5	a_R_5	a_R_3	A_R_1
a_S_1	A_S_3	a_S_5	A_S_5	A_S_1	a_S_3
bf_F_1	Bf_F_3	bf_F_5	Bf_F_5	Bf_F_1	bf_F_3
Bf_R_3	bf_R_1	Bf_R_5	bf_R_5	Bf_R_1	bf_R_3
Bf_S_5	bf_S_1	Bf_S_1	bf_S_3	Bf_S_3	bf_S_5
b_F_5	b_F_1	b_F_3	B_F_1	B_F_5	B_F_3
B_R_1	b_R_3	B_R_5	B_R_3	b_R_1	b_R_5
B_S_3	b_S_3	b_S_5	b_S_1	B_S_1	B_S_5
C_F_5	C_F_3	C_F_1	c_F_3	c_F_1	c_F_5
c_R_3	C_R_5	c_R_5	C_R_3	c_R_1	C_R_1
C_S_5	C_S_1	c_S_1	C_S_3	c_S_3	c_S_5
cs_F_3	Cs_F_3	Cs_F_5	cs_F_1	Cs_F_1	cs_F_5

Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Cs_R_1	Cs_R_5	Cs_R_3	cs_R_3	cs_R_1	cs_R_5
Cs_S_5	Cs_S_1	cs_S_5	cs_S_1	cs_S_3	Cs_S_3
D_F_3	d_F_5	d_F_3	D_F_5	d_F_1	D_F_1
d_R_1	D_R_3	d_R_5	d_R_3	D_R_5	D_R_1
D_S_5	D_S_3	d_S_5	d_S_3	d_S_1	D_S_1
ef_F_1	Ef_F_3	ef_F_3	Ef_F_1	Ef_F_5	ef_F_5
ef_R_1	ef_R_5	ef_R_3	Ef_R_5	Ef_R_3	Ef_R_1
ef_S_1	Ef_S_1	ef_S_5	ef_S_3	Ef_S_3	Ef_S_5
e_F_3	e_F_5	E_F_1	e_F_1	E_F_5	E_F_3
E_R_5	e_R_3	e_R_1	E_R_1	E_R_3	e_R_5
E_S_3	e_S_5	e_S_3	e_S_1	E_S_5	E_S_1
f_F_5	F_F_1	f_F_3	F_F_5	f_F_1	F_F_3
f_R_1	f_R_3	f_R_5	F_R_5	F_R_3	F_R_1
f_S_1	F_S_1	f_S_3	F_S_5	F_S_3	f_S_5
fs_F_3	Fs_F_3	fs_F_1	Fs_F_1	Fs_F_5	fs_F_5
fs_R_1	fs_R_3	fs_R_5	Fs_R_1	Fs_R_5	Fs_R_3
fs_S_5	Fs_S_5	Fs_S_3	fs_S_3	fs_S_1	Fs_S_1
g_F_1	g_F_5	G_F_3	G_F_1	G_F_5	g_F_3
g_R_3	G_R_5	g_R_1	G_R_3	G_R_1	g_R_5
g_S_3	G_S_5	G_S_1	g_S_5	g_S_1	G_S_3

Note. Chords are identified by Key_Inversion_Melody. Keys in upper case lettering are Major and those with lower case lettering are minor. An 'f' after an upper or lower case Key indicates flat; an 's' after and upper or lowercase Key indicates sharp; Inversion (R = Root, F = First, S = Second); Melody (1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice).

The 36 chords in each block, organised chromatically in Table C.1 are shown in the randomised order as heard by participant 1.

Table C.2.

Chords, in each of six blocks, heard by participant 1

Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
g_S_3	e_R_3	fs_F_1	Af_F_3	Cs_F_1	D_R_1
C_S_5	Cs_R_5	Bf_S_1	g_S_5	cs_R_1	Fs_S_1
g_F_1	Fs_S_5	ef_R_3	b_S_1	fs_S_1	A_R_1
e_F_3	e_F_5	d_F_3	D_F_5	F_S_3	C_R_1
fs_S_5	A_R_3	Cs_R_3	F_F_5	Bf_S_3	Ef_R_1
d_R_1	G_S_5	e_S_3	G_R_3	D_R_5	b_R_5
Af_S_5	C_F_3	cs_S_5	cs_R_3	F_R_3	c_F_5

Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
Cs_S_5	C_R_5	C_F_1	ef_S_3	a_R_3	E_F_3
f_S_1	G_R_5	b_S_5	e_F_1	d_F_1	Cs_S_3
b_F_5	Fs_F_3	A_R_5	fs_S_3	g_S_1	B_S_5
D_S_5	e_S_5	Af_F_1	Fs_F_1	af_R_3	E_S_1
c_R_3	af_S_3	Bf_R_5	B_R_3	E_S_5	bf_S_5
ef_S_1	fs_R_3	f_R_5	Fs_R_1	c_S_3	B_F_3
D_F_3	af_F_3	bf_F_5	bf_S_3	b_R_1	bf_F_3
Af_F_5	f_R_3	A_F_5	Ef_F_1	A_S_1	g_R_5
Bf_S_5	D_S_3	e_R_1	d_R_3	Ef_F_5	Af_S_1
g_R_3	Bf_F_3	b_F_3	e_S_1	G_F_5	f_S_5
Cs_R_1	Cs_F_3	ef_F_3	cs_F_1	Ef_R_3	bf_R_3
B_S_3	Cs_S_1	G_F_3	cs_S_1	E_F_5	fs_F_5
B_R_1	ef_R_5	g_R_1	G_F_1	B_F_5	ef_F_5
cs_F_3	C_S_1	f_F_3	a_R_5	Bf_R_1	c_S_5
bf_F_1	bf_R_1	a_S_5	Af_R_5	f_F_1	cs_R_5
fs_R_1	F_F_1	G_S_1	af_S_5	af_F_1	cs_F_5
a_R_1	b_S_3	B_R_5	A_F_3	Bf_F_1	Fs_R_3
Bf_R_3	A_F_1	Fs_S_3	d_S_3	c_F_1	e_R_5
a_F_1	Ef_S_1	Af_R_3	C_S_3	cs_S_3	F_F_3
f_R_1	g_F_5	fs_R_5	A_S_5	a_F_3	af_F_5
af_R_5	d_F_5	E_F_1	bf_R_5	Fs_R_5	g_F_3
a_S_1	bf_S_1	f_S_3	F_R_5	c_R_1	af_R_1
f_F_5	b_R_3	Af_S_3	c_F_3	B_S_1	a_S_3
ef_R_1	Ef_F_3	d_S_5	B_F_1	E_R_3	F_R_1
E_S_3	D_R_3	d_R_5	Bf_F_5	G_R_1	a_F_5
C_F_5	A_S_3	ef_S_5	C_R_3	Ef_S_3	D_F_1
E_R_5	Af_R_1	c_S_1	Ef_R_5	Fs_F_5	D_S_1
ef_F_1	b_F_1	Cs_F_5	F_S_5	d_S_1	Ef_S_5

Note. Chords are identified by Key_Inversion_Melody. Keys in upper case lettering are Major and those with lower case lettering are minor. An ‘f’ after an upper or lower case Key indicates flat; an ‘s’ after and upper or lowercase Key indicates sharp; Inversion (R = Root, F = First, S = Second); Melody (1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice).

Table C.3 show the randomisation of the 36 chords from Block 1 as heard by participants 1 and 3. The same 36 chords are presented to both participants, but there order of presentation differs.

Table C.3.

36 chords in Block 1 for participant 1 and 3

Participant 1	Participant 3
g_S_3	C_S_5
C_S_5	d_R_1
g_F_1	fs_S_5
e_F_3	B_S_3
fs_S_5	Af_S_5
d_R_1	af_R_5
Af_S_5	a_S_1
Cs_S_5	ef_S_1
f_S_1	g_R_3
b_F_5	Cs_S_5
D_S_5	D_F_3
c_R_3	f_S_1
ef_S_1	C_F_5
D_F_3	Cs_R_1
Af_F_5	fs_R_1
Bf_S_5	Bf_S_5
g_R_3	D_S_5
Cs_R_1	fs_F_3
B_S_3	c_R_3
B_R_1	Af_F_5
cs_F_3	ef_F_1
bf_F_1	e_F_3
fs_F_3	E_R_5
fs_R_1	cs_F_3
a_R_1	ef_R_1
Bf_R_3	a_R_1
a_F_1	g_S_3
f_R_1	f_F_5
af_R_5	B_R_1
a_S_1	Bf_R_3
f_F_5	E_S_3
ef_R_1	a_F_1
E_S_3	g_F_1
C_F_5	b_F_5

Participant 1	Participant 3
E_R_5	f_R_1
ef_F_1	bf_F_1

Note. Chords are identified by Key_Inversion_Melody. Keys in upper case lettering are Major and those with lower case lettering are minor. An ‘f’ after an upper or lower case Key indicates flat; an ‘s’ after and upper or lowercase Key indicates sharp; Inversion (R = Root, F = First, S = Second); Melody (1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice).

Table C.4 shows the three possible Inversions equally distributed in each block. Other than Blocks 1 and 4, the three possible Melody notes were not as evenly distributed among the 6 blocks. In Block 2, 44% of the chords were Melody 3. In Blocks 3 and 6, 42% of the chords were Melody 5. In Block 5, 47% of the chords were Melody 1. Other than Block 6, chord Quality was unevenly represented.

Table C.4.

Quantity of chords in each block by Inversion, Melody, and Quality

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
INVERSION						
Root	12	12	12	12	12	12
First	12	12	12	12	12	12
Second	12	12	12	12	12	12
MELODY						
1	14	10	9	11	17	11
3	10	16	12	13	11	10
5	12	10	15	12	8	15
QUALITY						
Major	14	21	15	20	20	18
minor	22	15	21	16	16	18

Randomising the order of block presentation and also randomising the order of chord presentation within each block addresses any concerns regarding the possible effect of the uneven distribution of Melody and chord Quality within blocks.

APPENDIX D: EXPLANATION OF STATISTICAL TERMS AND PROCEDURES

Factors and Levels

There were 4 factors (or dependent variables) being tested in this study. They are Inversion, Melody, Quality, and Expertise. Inversion and Melody are factors with 3 levels. The levels of Inversion are Root, First, and Second. The levels of Melody are 1, 3, and 5. Quality and Expertise are factors with 2 levels. The levels of Quality are Major and minor. The levels of Expertise are Expert and Novice. The independent variable, the variable being measured, was perceived tension.

Both Within-subjects and Between-subjects factors were tested. Inversion, Melody, and Quality are Within-subjects factors because all participants were tested on all levels of these factors. Expertise is a Between-subjects factor because the groups of participants were not the same for each level. Thus, this study tested the influence of 3 Within-subjects factors and 1 Between-subjects factor upon perceived tension due to chord formations heard devoid of a tonal and musical context.

Statistical Tests[422]

Descriptive Statistics

Descriptive Statistics summarise characteristics of the data. In this study, descriptive statistics were reported for each of the 18 chord formations.[423] The statistics reported by SPSS 22 include, but are not limited to: Mean, Median, Variance, Standard Deviation, Margin of Error, and Skewness. Different plots of the data may also be requested. These include Histograms, Boxplots, and Normal Q-Q plots.

1. Mean: a measure of central tendency such that all recorded values of perceived tension for a chord formation are summed and divided by the number of recorded values. For example, all the recorded values for the chord formation of F3n were summed. The sum is then divided by the number of responses. Ideally, the number of responses would be 82 (the number of participants in the study). Occasionally, participants were late in attempting to record their rating. The computer, in this case, does not record the rating. The sum of the responses is divided by the number of recorded responses.
2. Median: a measure of central tendency, the median is the rating for which 50% of the ratings are above and 50% of the ratings are below. To obtain the median, the ratings are arranged hierarchically, from lowest to highest. The median is the middle value. For example, the median of 81 responses would be the value found in the 41st position. The median of 82 responses is the sum of value in the 41st position plus the value in the 42nd position. The median is this sum divided by 2. The median is less affected by skewed data and outliers than is the mean.
3. Variance and Standard Deviation: these are measures of the spread of the data around the mean. The larger the number the greater the spread around the mean. A smaller number indicates more consistency among the ratings.
4. 95% Margin of Error: we are 95% confident the true mean is found between the mean minus the margin of error and the mean plus the margin of error. 5% of the time the true mean will be outside this range of values.

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[422] All the statistical tests used in this study were performed using IBM's SPSS version 22.
[423] R1M, R1n, R3M, R3n, R5M, R5n, F1M, F1n, F3M, F3n, F5M, F5n, S1M, S1n, S3M, S3n, S5M, and S5n where R = Root, F = First Inversion, S = Second Inversion, 1 = Root in Melody, 3 = third of chord in Melody, 5 = fifth of chord in Melody, M = Major, and n = minor. The Between-subjects levels (Expert and Novice) were combined as there was no effect of Expertise.

5. Skewness: describes the asymmetry of a distribution of values in comparison with a normal (or bell shaped) distribution. Skew values closer to zero indicate more symmetrical distributions and thus closer to a normal distribution. Skew values further from zero indicate less symmetrical distributions and thus farther from a normal distribution. As a rule, skewness values between -1 and -.5 or between 1 and .5 are considered to describe moderately skewed distributions. Skewness values less than -1 or greater than 1 are considered to describe highly skewed distributions. The method used to determine degree of skewness in Appendix E (Outliers, Skewness, and the Violation of Assumption of Normal Distribution) is to compare the skewness statistic to twice the standard error of the skewness value.

A distribution with most values piled to the left, like those of Major Quality chords, is identified as skewed to the right. A distribution with most values piled to the right, like those of minor Quality chords, is identified as skewed to the left. The direction of the skew is not defined by the location of the pile of data points but instead by the location of the tail indicating fewer data points. (See Figure D.1.)

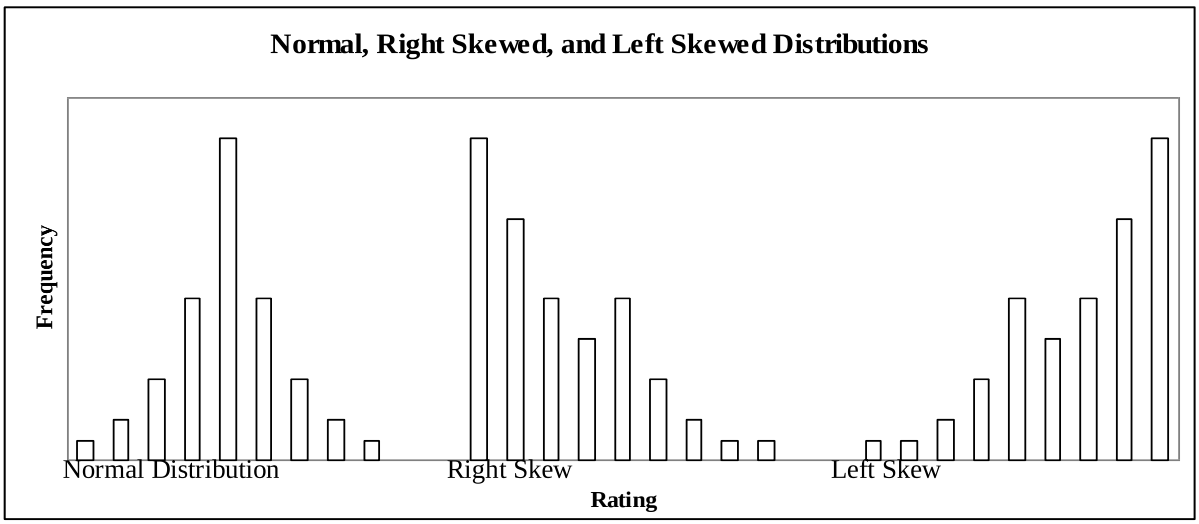

Figure D.1. Examples of Normal, Right Skewed, and Left Skewed distributions.

Three Graphical Depictions of Data Distribution

1. Histogram: similar to the bar graph in Figure I.1, a histogram visually depicts the frequency of each rating for each chord formation. Like the bar graph above, the histogram portrays the distribution of the data. Figure D.2 is the histogram, created in SPSS 22, for the chord formation R3M (Inversion: Root position, Melody: 3rd of the chord in the Melody, Quality: Major). It demonstrates the right skewed distribution of the data where very few ratings are found above 40 and more than 50% of the ratings are 25 or below. Figure D.3 is the histogram, created in SPSS 22, for the chord formation F3n (Inversion: First, Melody: 3rd of the chord in the Melody, Quality: minor). It demonstrates a normal distribution of the data.

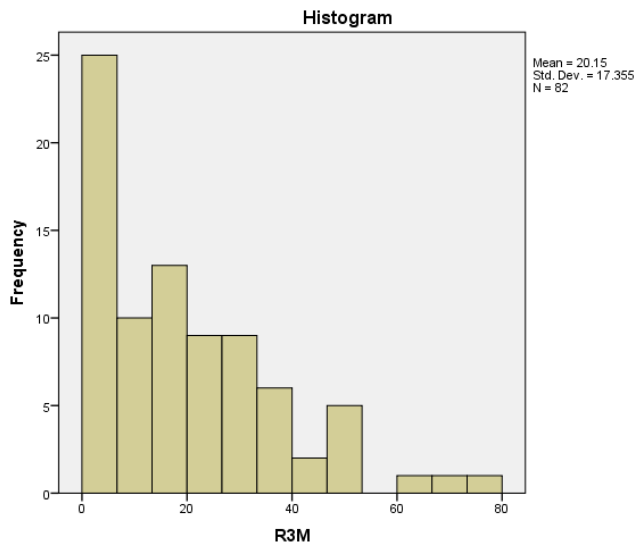

Figure D.2. Histogram for chord formation R3M as created by SPSS 22, demonstrating right skewness (Skewness = 1.039).

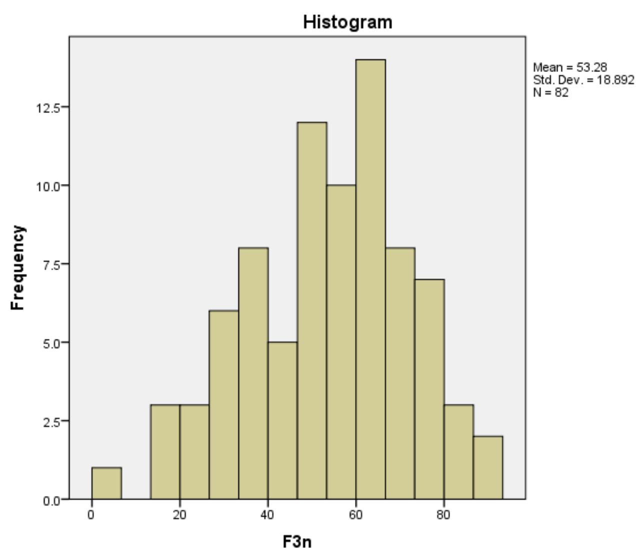

Figure D.3. Histogram for chord formation F3n as created by SPSS 22, demonstrating a distribution accepted as normal by SPSS 22 (Skewness = .302).

2. Boxplot: a boxplot shows the range of the data (from the lowest non-outlier data point to the highest non-outlier data point), the median, which data points (if any) are outliers, and the distribution of the data. A first glance at the boxplot for R3M in Figure D.4 shows a range of data points from 0 to round 60, with 50% of data points found, approximately, between 10 and 35. 25% of the data points are between 0 and 10. Another 25% are between 35 and 60. The median, indicated by the vertical solid line within the box, is around 18. Furthermore, Figure D.4 identifies two outliers, i.e., participants 28 and 53. The conclusion, from looking at this boxplot, is the data is skewed to the right.

Compare this with the boxplot for F3n in Figure D.5. Two things are immediately evident. There are no outliers, and the box appears near the middle of the data as the two lines found before and after the box are near-equal in length. We can approximate numbers for these observations. The range of these data points is approximately 5 to 95. 50% of the data points fall between 40 and 70; 25% are between 5 and 40; 25% are between 70 and 95. The median is approximately 58 and there are no outliers.

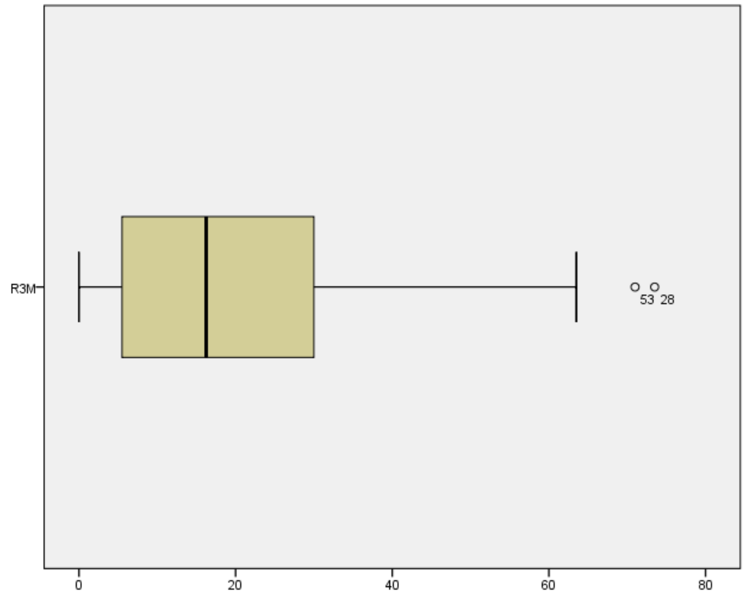

Figure D.4. Boxplot for chord formation R3M as created by SPSS 22, demonstrating right skew (Skewness = 1.039).

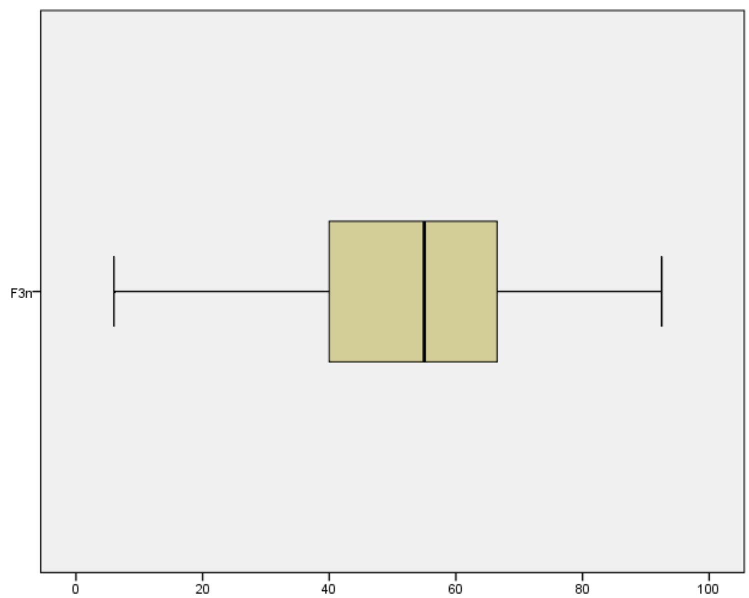

Figure D.5. Boxplot for chord formation F3n as created by SPSS 22, demonstrating normal distribution (Skewness = .302).

3. Normal Q-Q plot: a Q-Q (Quantile-Quantile) plot is another method visually depicting whether a data set came from a normally distributed population. The solid lines in Figures D.6 and D.7 represent the values expected if the data is normally distributed. The open circles represent the actual distribution of the ratings for the chord

formations R3M and R3n. We can see how the data in Figure D.7 follows the solid line of the expected normal distribution. The same does not occur in Figure D.6 where we find with ratings above 50 moving away from the expected values.

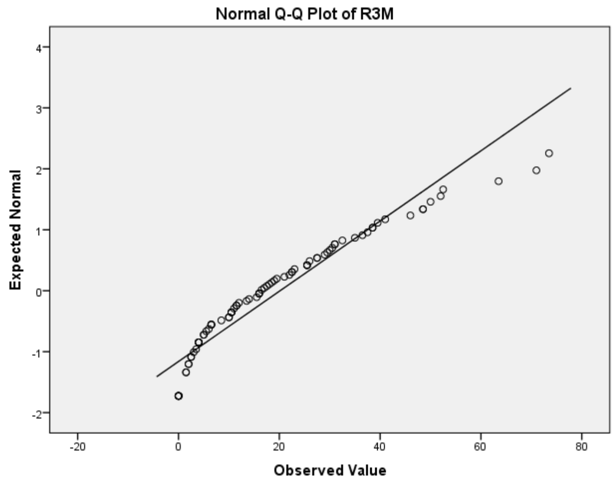

Figure D.6. Q-Q plot for chord formation R3M as created by SPSS 22, demonstrating right skew (Skewness = 1.039).

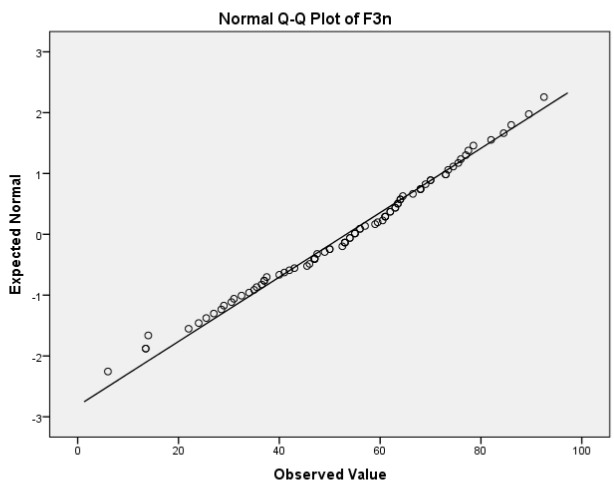

Figure D.7. Q-Q plot for chord formation F3n as created by SPSS 22, demonstrating normal distribution (Skewness = .302).

Two Statistical Procedures

1. Analysis of Variance (ANOVA): a statistical test used to determine whether there is a significant difference between the means of two or more factors. In this study there are 3 within-subjects factors (Inversions x Melody x chord Quality) and 1 between-subjects factor (Expertise). ANOVA determines the probability the change in ratings is due to each factor alone (Main effect), and the probability the change in ratings is due to two or more factors acting together (Interaction). An *F* (obtained) statistic is calculated for each main effect and interaction. The degrees of freedom (*df*) are used to locate the *F* (critical value) statistic found in the table of critical values. If the *F* (obtained) statistic is larger than the *F* (critical value) statistic, we can conclude the factor in question is

affecting participants' rating of perceived tension. The same is true when looking for evidence of the effect of two or more factors acting together to affect ratings of perceived tension. The *p*-value associated with each *F* (obtained) statistic indicates the probability the results are due to chance and not the main effect of the factor or the interaction of factors. Degrees of freedom depend upon the number of scores free to vary. There are two parts to reporting degrees of freedom for ANOVA. The first part is dependent upon the number of levels free to vary. The second part is dependent upon the number of participants.

2. Paired sample *t*-test: a statistical test used to determine whether there is a significant difference between the means of two independent samples. A *t* (obtained) statistic is calculated and, like the *F* (obtained) statistic above, is compared with *t* (critical value) statistic. The degrees of freedom (*df*) are used to locate the *t* (critical value) statistic found in the table of critical values. If the *t* (obtained) statistic is larger than the *t* (critical value) statistic, we can conclude the means of the two samples in question are different and the two factors or levels differently affect participants' rating of perceived tension. The *p*-value associated with each *t* (obtained) statistic indicates the probability the results are due to chance and not the effect of the factor or level. Degrees of freedom depend upon the number of scores.

Two Calculations of Effect Size

1. Eta squared (η^2): is one measure of effect size that can be applied to ANOVA results. It is a measure of the size of effect an independent variable (Inversion, Melody, Quality, Expertise, and their interactions) has upon the dependent variable (perceived tension). In other words, eta squared provides the proportion of change in the dependent variable (perception of tension) explainable by an independent variable (main effects and interactions of Inversion, Melody, Quality, and Expertise).
2. Cohen's *d*: is one measure of effect size that can be applied to *t*-test results. It is dependent upon the difference between two means and their pooled standard deviation.[424] Among the ways Cohen's *d* can be interpreted is as the amount of overlap between their population distributions. A lower Cohen's *d* indicates the means of the two populations are closer together resulting in considerable overlap of their distributions. Thus, it is less likely the two means represent two different populations. A larger Cohen's *d* indicates the means of the two populations are farther apart resulting in less overlap of their distributions. Thus, it is more likely the means represent two different populations. In this study, it is a measure of the size of effect an independent variable (Inversion, Melody, Quality, Expertise, and/or their levels) has upon the dependent variable (perceived tension) in comparison to another independent variable (Inversion, Melody, Quality, Expertise, and/or their levels).

Mauchly's Test of Sphericity

The assumption of Sphericity is important for repeated measures ANOVA like the one in this study. Sphericity means the variance[425] between the means of all levels of all factors is the same. For example, if the variances for R1M and R3M are equal to the variance for S5n and F1M, the assumption of sphericity is not violated.

---

[424] Cohen's $d = (M_1 - M_2)/SD_{\text{pooled}}$, where *M* is mean and *SD* is standard deviation. $SD_{\text{pooled}} = \sqrt{[\sum(x_1 - xbar_1)^2 + \sum(x_2 - xbar_2)^2]/(n_1 + n_2 - 2)}$, where *x* is a data point, *xbar* is the sample mean associated with each sample, and *n* represents the sample size. SD_{pooled} can also be determined by $\sqrt{[(SD_1^2 + SD_2^2)/2]}$.
[425] Variance measures the spread of the data. It is calculated by averaging the squared deviation from the mean of each data point. For example, if the data points are 1, 2, and 3, the mean is 2. The variance is $[(1-2)^2 + (2-2)^2 + (3-2)^2]/3 = 0.667$.

If the variance is unequal the assumption of sphericity is violated a correction must be made to the degrees of freedom (*df*) used to determine the *F* (critical) statistic. The degrees of freedom are smaller with the correction. This results in a larger *F* (critical) value, thus requiring a larger *F* (obtained) in order for there to be evidence of an effect or interaction. SPSS 22 reports Mauchly's test of sphericity. If the *p*-value is not significant ($p > .05$), no correction to the degrees of freedom is needed. It the *p*-value is significant ($p < .05$) a correction to the degrees of freedom in required.

APPENDIX E: OUTLIERS, SKEWNESS, AND THE VIOLATION OF ASSUMPTION OF NORMAL DISTRIBUTION

The Shapiro-Wilk test for normality performed on the means of the collected data revealed $p < .05$ for all chord formations, regardless of Inversion, Melody, or chord Quality. This indicates non-normal distributions. The histograms of all major chord formations were skewed right (indicating a clustering of ratings in lower tension range), and those of all minor chord formations were skewed left (indicating a clustering of ratings in higher tension range). The Shapiro-Wilk test performed on the medians obtained from the collected data revealed 5 of 18 chord formations with $p > .05$. F1M,[426] F3M, R3n, R5n, and F3n were normally distributed. The histograms of the remaining major chord formations were skewed to the right, and the histograms of the remaining minor chord formations were skewed to the left. Because the data were not skewed in the same direction, data transformation does not work. For example, a log10 transformation on the medians of right skewed R1M, R3M, R5M, and left skewed R1n and F1n did not result in normal distributions.[427]

Boxplots, created by SPSS 22, for the medians of each of the 18 chord formations revealed 21 outliers[428] spread over 9 chord formations. The outliers were removed and descriptive statistics were obtained. Table E.1 shows the 18 chord formations and the distributions obtained from the median data, with and without outliers. Removing the outliers resulted in a normal distribution for 3 more chord formations (S1n, S3n, and S5n). Unfortunately, removal of outliers also resulted in a decrease in total number of participants as the statistical software SPSS removes all the ratings of a participant who has one or more missing data points. The total number of participants when outliers are removed is 68 instead of the original 82. The reduction in sample size could lead to a reduction in the power of statistical tests.[429] Taking into account the outcomes of the various approaches, I decided to perform statistical tests on the median of the data (n=82), as the median better represents skewed distributions than does the mean. For comparison of outcomes, ANOVA was performed on the data without outliers (n=68). These results and their implications are found in Appendix F.

It is possible violating the assumption of normally distributed data could be problematic when performing an analysis of variance (ANOVA). I say 'possible' because, presently, there is no consensus among statisticians regarding the effect of violating the normality assumption when performing an ANOVA. Some report ANOVA is robust to this violation while others disagree. The data were analysed using IBM's statistical software SPSS version

[426] The nomenclature is as follows: R for Root position, F for First inversion, S for Second inversion; 1 for the root of the chord in the soprano, 3 for the third of the chord in the soprano, 5 for the fifth of the chord in the soprano; M for Major chord quality and n for minor chord quality.

[427] These chord formations were chosen out of the remaining skewed chord formations as trials for the transformation.

[428] R1M (1-high), R3M (2-high), S3M (1-high), S5M (1-high), R5n (1-low), F1n (8-low), F5n (1-low), S1n (2-low), S3n (3-low), and S5n (1-low). Of the 21 outliers, 6 were due to Novice participants and 15 due to Expert participants. Five outliers were associated with Major chord Quality and 16 with minor chord Quality.

[429] G*Power, a programme written by Franz Faul of the University of Kiel in Germany, was used to determine the sample size for this study. To calculate sample size, G*Power requires the researcher to input values for effect size (.1 or small), alpha (.05), power (.95), number of groups (1), number of measurements (3x3x2 = 18), correlation among repeated measures (default = .5), and nonsphericity correction (1). With these parameters, G*Power determined the sample size to be 82 participants. If the effects size was changed from small to between small and medium (.15), G*Power determined the ideal sample size to be 37 participants. Thus, the removal of outliers, with its resulting sample size of 68, could be considered a reasonable number of participants.

22. The manual for SPSS 22 states, "ANOVA and MINQUE do not require normality assumptions. They are both robust to moderate departures from the normality assumption."[430] This view is supported by Berkovits, Hancock, and Nevitt (2000) who write, "If nonnormality occurs as the sole violation, both the traditional *F* and multivariate T^2 appear most robust (even though they are technically dependent on the assumption of normality)."[431] Vallejo et al (2010) concur—"The execution of ANOVA approach was considerably influenced by the presence of heterogeneity and lack of sphericity, but scarcely affected by the absence of normality."[432]

Table E.1.

Distribution of data by chord formation with and without outliers

Chord formation	Distribution: With Outliers (n=82)	Distribution: Without Outliers (n=68)
R1M	Right	Right
R3M	Right	Right
R5M	Right	Right
F1M	Normal	Normal
F3M	Normal	Normal
F5M	Right	Right
S1M	Right	Right
S3M	Right	Right
S5M	Right	Right
R1n	Left	Left
R3n	Normal	Normal
R5n	Normal	Normal
F1n	Left	Left
F3n	Normal	Normal
F5n	Left	Left
S1n	**Left**	**Normal**
S3n	**Left**	**Normal**
S5n	**Left**	**Normal**

Note. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor.

[430] *IBM SPSS Advanced Statistics 22* from http://www.01.ibm.com/support/docview.wss?uid=swg2703847 downloaded June 1, 2015. An explanation of how the median data from this study could be viewed as falling within the category of 'moderate departure' is found in the next paragraph.

[431] Ilona Berkovits, Gregory Hancock, and Jonathan Nevitt, "Bootstrap resampling approaches for repeated measure designs: relative robustness to sphericity and normality violations." *Educational and Psychological Measurement* Vol. 60, no. 6 (2000): 890.

[432] Guillermo Vallejo,et al, "Analyzing repeated measures using resampling methods." *Anales de Psicología* Vol. 26, no. 2 (2010): 400.

One method of estimating the degree of normality violation is to compare the skewness value with twice the standard error of the skewness. If the skewness is near twice the standard error, the distribution is considered normal. The further away the skewness value is from twice the standard error, the further away the distribution is from normal. The means of the median ratings with and without outliers is summarised in Table E.2. Twice the standard error of the skewness for the chords including outliers is .523, and .582 for the distributions without outliers. The values presented in bold could be considered normally distributed or 'moderate departures from the normality assumption.'

Table E.2.

Skewness value for all chord formations with and without outliers

Skewness (with)	Chord formation	Skewness (without)
.781	R1M	**.466**
1.039	R3M	.72
.515	R5M	**.49**
$.091^{N}$	F1M	$.087^{N}$
$.213^{N}$	F3M	$.183^{N}$
.522	F5M	**.615**
.42	S1M	**.372**
.788	S3M	**.628**
.754	S5M	.677
-.834	R1n	-.97
$-.32^{N}$	R3n	$-.217^{N}$
$-.486^{N}$	R5n	$-.314^{N}$
-1.051	F1n	**-.524**
$-.302^{N}$	F3n	$-.036^{N}$
-.767	F5n	**-.584**
-.996	S1n	$-.449^{N}$
-.735	S3n	$-.274^{N}$
-.623	S5n	$-.291^{N}$

Note. Skewness values for the mean of median ratings with and without outliers. The absolute values in bold typeface, when compared with twice the standard error of skewness, could be considered 'moderate departures' from a normal distribution. Superscript ^{N} indicates chord formations declared normally distributed by Shapiro-Wilk test. Note: Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor.

The number of chords, when including outliers, now violating the assumption of normality is reduced from 13/18 to 8/18. The number of chords now violating the assumption of normality, when not including outliers, can be reduced from 8/18 to 3/18. To determine the consequences, if any, of drawing conclusions using the data with outliers, ANOVA was performed also on the median data without outliers. Other than a slight increase in effect size of the main effects and interactions, and a change in the *p*-value for the Inversion*Quality*Expertise interaction, increasing the number of normally distributed chord formations has no effect on the final outcome.[433]

[433]Details on the results of ANOVA on data without outliers, and a comparison to the output with ANOVA on data with outliers, is found in Appendix F.

APPENDIX F: RESULTS OF ANOVA PERFORMED ON MEANS OF MEDIANS OF DATA WITHOUT OUTLIERS

Boxplots, from statistical software SPSS 22, of participant means of medians perceived tension for each of the 18 chord formations revealed 21 outliers[434] spread over 9 chord formations. The outliers were removed, descriptive statistics were obtained, and ANOVA performed on these data. Table F.1 gives the means of medians perceived tension, without outliers (N= 68), for each chord formation and its associated standard deviation. A graph illustrating these results and confidence intervals (95%), for all chord formations is shown in Figure F.1. For comparison, Figure F.2 shows means of medians perceived tension with outliers and 95%confidence intervals, for all chord formations. The two levels of expertise (Novice and Expert) are combined. The rational for this, as with data with outliers, is because ANOVA determined there was no effect of Expertise. Data with or without outliers show all minor chord formations are perceived as tenser than were all Major chord formations. Generally, removal of outliers resulted in a higher mean of medians tension value (for 14/18 chord formations) and smaller standard deviations.

Table F.1.

Means of medians perceived tension and standard deviation, without outliers, for all chord formations

Chord formation	M	SD	Chord formation	M	SD
R1M	25.13	18.49	R1n	60.74	16.09
R3M	19.82	15.16	R3n	51.84	15.7
R5M	24.42	15.68	R5n	52.99	15
F1M	37.34	18.34	F1n	62.28	13.33
F3M	28.62	15.94	F3n	56.05	15.63
F5M	25.43	15.61	F5n	57.15	14.72
S1M	36.14	20.72	S1n	66.01	14.06
S3M	27.8	16.53	S3n	62.72	15.27
S5M	23.01	14.17	S5n	61.37	17.64

Note. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor.

[434] R1M (1-high), R3M (2-high), S3M (1-high), S5M (1-high), R5n (1-low), F1n (8-low), F5n (1-low), S1n (2-low), S3n (3-low), and S5n (1-low)

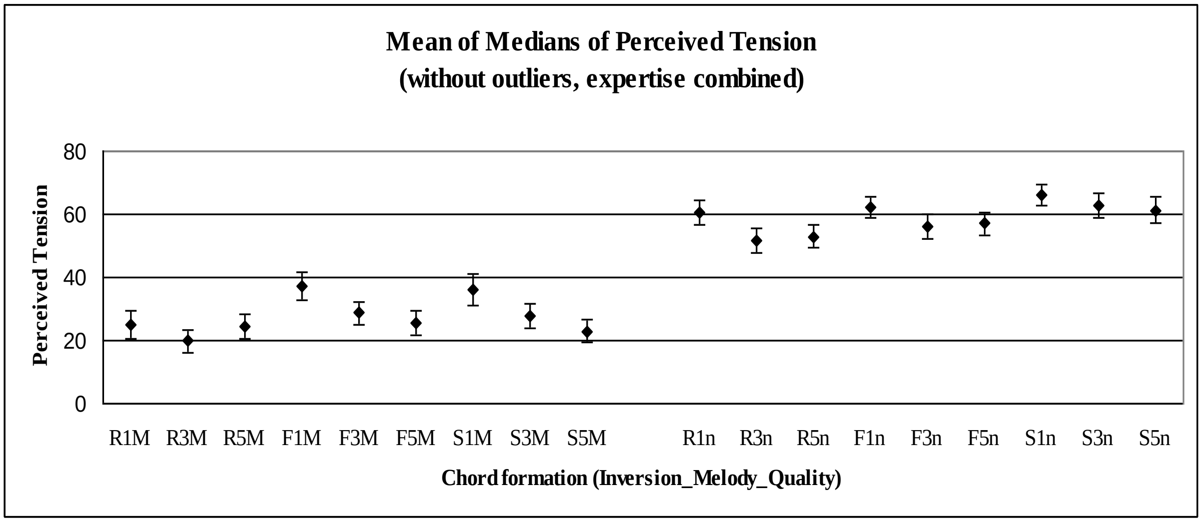

Figure F.1. Mean of medians perceived tension, without outliers, (Expertise combined) and 95% confidence intervals, by chord formation. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 =fifth of chord in top voice; Quality: M = Major, n = minor.

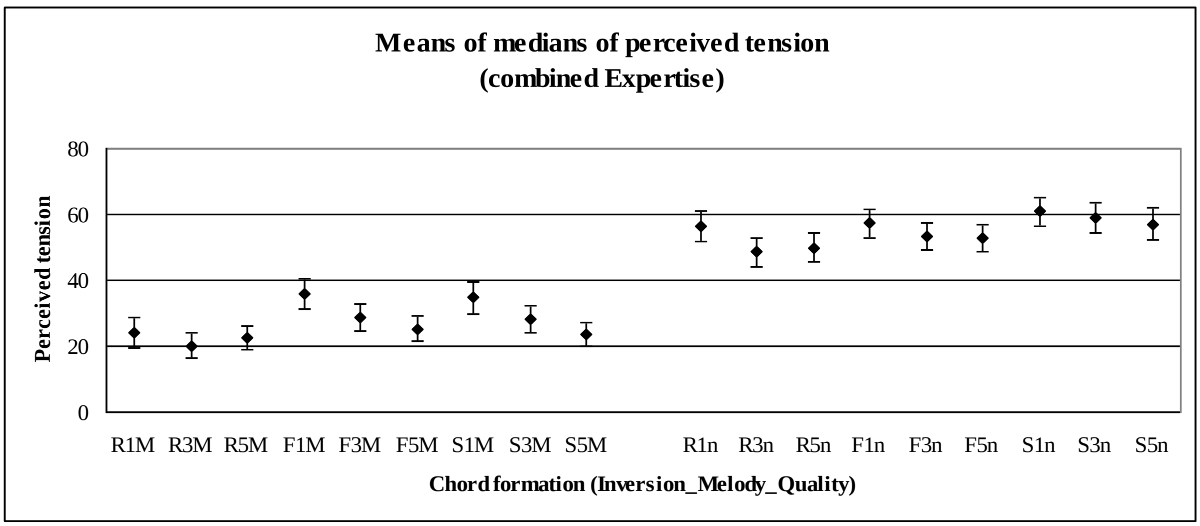

Figure F.2. Mean of medians perceived tension, with outliers, (Expertise combined) and 95% confidence intervals, by chord formation. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 =fifth of chord in top voice; Quality: M = Major, n = minor.

ANOVA performed on the medians of the raw data, with and without outliers (summarised in Table F.2), results in the presence of similar main effects and interactions. The level of significance (with outliers = .002, and without outliers = .001) differ for the three-way interaction Inversion*Melody*Quality. Both *p*-values, however, indicate the presence of an interaction. An important difference is found in the results of the three-way interaction Inversion*Quality*Expertise. With outliers included in the data, Inversion*Quality*Expertise interact in participants' perception of tension evidenced by the nonparallel, intersecting lines in Figure F.3. With outliers removed, Expertise does not interact with, or has no effect upon, participant's perception of tension in the Inversion*Quality interaction. The nonintersecting lines of Figure F.4 demonstrate the lack of interaction.

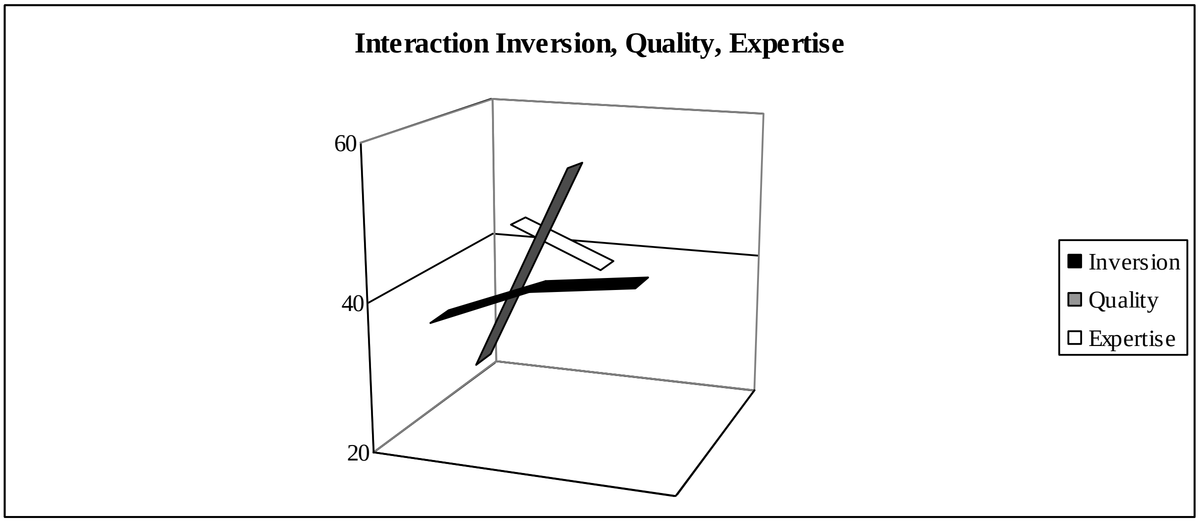

Figure F.3. Interaction of Inversion (Root, First, Second), Quality (Major, minor), and Expertise (Novice, Expert) from data with outliers.

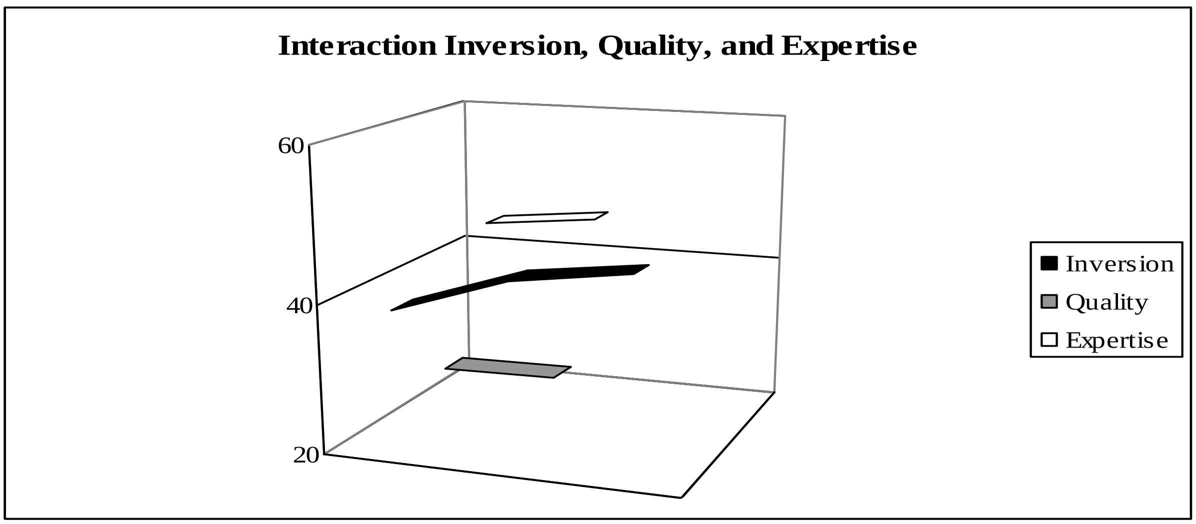

Figure F.4. Interaction of Inversion (Root, First, Second), Quality (Major, minor), and Expertise (Novice, Expert) from data without outliers.

Table F.2.

Analysis of Variance for Perceived Tension in Chord Formations

	With outliers			Without outliers		
Source	df	*F*	η^2	df	*F*	η^2
Between Subjects						
Expertise	1	3.4	.012	1	.75	.002
Error (Expertise)	80			66		
Within Subjects						
Inversion	2	45.16•••	.015	2	56.98•••	.017
Error (Inversion)	160			132		
Melody	1.81	22.48•••	.013	1.78	31.74•••	.02
Error (Melody)	144.79			117.39		
Quality	1	214.65•••	.334	1	288.44•••	.47
Error (Quality)	80			66		
Inversion*Melody	3.56	3.02•	.002	3.21	3.61•	.0024
Error (Inversion*Melody)	248.48			212.17		
Inversion*Quality	2	9.14•••	.003	2	9.94•••	.0031
Error (Inversion*Quality)	160			132		
Melody*Quality	2	2.25	.0006	2	1.72	.0005
Error (Melody*Quality)	160			132		
Inversion*Expertise	2	.65	.0002	2	2.98	.0009
Error (Inversion*Expertise)	80			66		
Melody*Expertise	2	3.62•	.0021	2	4.09•	.0026
Error (Melody*Expertise)	80			66		
Quality*Expertise	1	.3	.0005	1	1.18	.002
Error (Quality*Expertise)	80			66		
Inversion*Melody*Quality	**4**	**4.42••**	**.002**	**4**	**6.63•••**	**.0039**
Error (Inversion*Melody*Quality)	320			264		
Inversion*Melody*Expertise	4	1.0	.0005	4	.56	.0004
Error (Inversion*Melody*Expertise)	80			264		
Inversion*Quality*Expertise	**2**	**4.32•**	**.001**	**2**	**1.76**	**.0006**
Error (Inversion*Quality*Expertise)	80			66		
Melody*Quality*Expertise	2	.81	.0002	2	1.07	.0003
Error (Melody*Quality*Expertise)	80			66		
Inversion*Melody*Quality*Expertise	4	1.39	.0007	4	1.22	.0007
Error (Inversion*Melody*Quality*Expertise)	80			66		

Note. •$p < .05$, ••$p < .002$, •••$p < .001$. Bolded entries indicate differing results.

Of the 21 outliers identified by SPSS 22, 6 were due to Novice participants and 15 due to Expert participants. Five outliers were associated with Major chord Quality and 16 with minor chord Quality. The graphs at Figures F.5 and F.6 show the means of the medians of perceived tension, with and without outliers, by Expertise. Not surprisingly, removal of outliers has the most effect for minor Quality chord formations, bringing the ratings of Novice and Expert participants closer together. Removal of outliers does not change the overall shape or trend in ratings when compared to the shape and trend of ratings with outliers. This observation is borne out by the complementary results of ANOVA, with and without outliers (Table F.2). A two-tailed paired samples *t*-test performed on the means of the medians, $t(8) = 22.05$, $p < .0001$, indicates is it unlikely the relationship between the chord formations from the two sets of data is different. Since removal of outliers (N = 68) did not appear to alter the results of data analysis to a meaningful degree, and retaining outliers gave more power to the results (due to increased sample size), ANOVA and subsequent statistical tests were performed on the means of the medians of the original number of participants (N = 82).

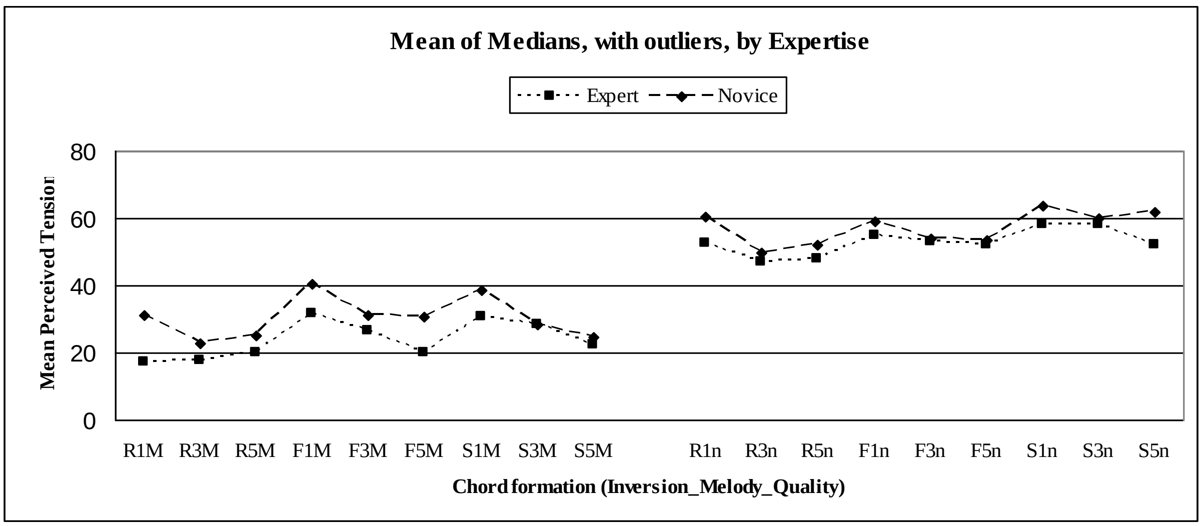

Figure F.5. Mean of medians perceived tension, with outliers, by Expertise, by chord formation. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major, n = minor.

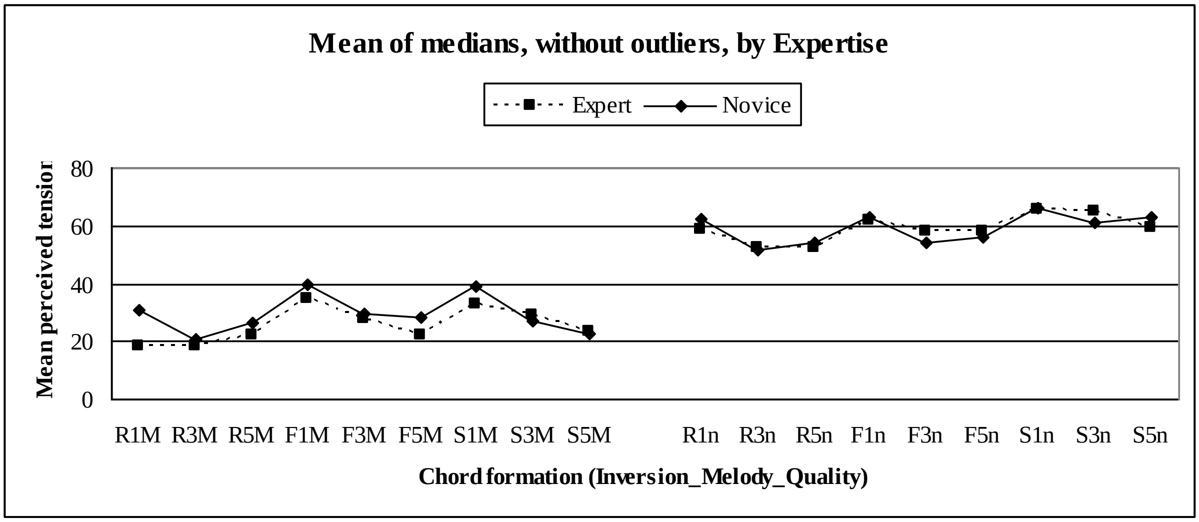

Figure F.6. Mean of medians perceived tension, without outliers, by Expertise, by chord formation. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice; Quality: M = Major, n = minor.

APPENDIX G: TABLES OF DATA FOR FIGURES IN CHAPTER 4

Table G.1.

Data table corresponding to Figure 4.1: Means of median perceived tension for Major Quality chord formations and 95% Confidence Intervals

Chord formation	Expert	MOE	Novice	MOE
R1M	17.41	6.11	30.98	6.12
R3M	17.73	5.31	22.57	5.6
R5M	19.98	5.16	25.24	5.41
F1M	31.81	6.78	40.26	6.03
F3M	26.39	6.07	31.02	4.96
F5M	20.08	4.71	30.51	5.48
S1M	30.76	7.28	38.77	6.2
S3M	28.23	6.06	28.27	5.72
S5M	22.54	5.05	24.71	4.98

Note. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: M = Major; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error.

Table G.2.

Data table corresponding to Figure 4.2: Means of median perceived tension for minor Quality chord formations and 95% Confidence Intervals

Chord formation	Expert	MOE	Novice	MOE
R1n	52.69	7.01	60.3	6.19
R3n	47.2	6.9	49.7	5.49
R5n	47.96	6.99	51.99	4.75
F1n	55.1	7.43	59.28	5.27
F3n	52.82	6.95	53.74	4.86
F5n	52.17	6.92	53.4	5.16
S1n	57.91	7.85	63.89	4.19
S3n	57.99	7.65	60.02	4.81
S5n	52.04	7.49	62.01	5.98

Note. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Quality: n = minor; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error.

Table G.3.

Data table corresponding to Figure 4.3 Difference of means of median perceived tension and 95% CI for Inversion

Inversion	Difference of means	SD	MOE	*r*
R & F	5.22	7.15	1.57	.869
R & S	6.94	7.28	1.6	.862
F & S	1.71	6.12	1.345	.902

Note. Inversion: R = Root, F = First, S = Second; SD = Standard Deviation of the difference; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

Table G.4.

Data table corresponding to Figure 4.4 Difference of means of median perceived tension and 95% CI for Melody

Melody	Difference of means	SD	MOE	*r*
M1 & M3	5.29	10.46	2.3	.773
M1 & M5	6.38	9.7	2.13	.808
M3 & M5	1.09	.85	1.7	.829

Note. Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; SD = Standard Deviation of the difference; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

Table G.5.

Data table corresponding to Figure 4.5: Difference of means of median perceived tension by chord Quality and 95% Confidence Intervals

Quality	Mean	MOE	*r*
minor	55.02	5.7	
Major	27.07	3.72	
Difference	27.95	3.78	.412

Note. MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

Table G.6.

Data table corresponding to Figure 4.6: Difference of means of median perceived tension by Inversion and Major chord Quality with 95% Confidence Intervals

Inversion	Difference of means	SD	MOE	*r*
R & F	7.69	10.34	2.27	.802
R & S	6.56	9.99	2.2	.8
F & S	1.13	9.27	2.33	.83

Note. Inversion: R = Root, F = First, S = Second; SD = Standard Deviation of the difference; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

Table G.7.

Data table corresponding to 4.7: Difference of means of median perceived tension by Inversion and minor chord Quality with 95% Confidence Intervals

Inversion	Difference of means	SD	MOE	*r*
R & F	2.75	9.94	2.18	.836
R & S	7.31	9.82	2.16	.848
F & S	4.56	7.96	1.75	.898

Note. Inversion: R = Root, F = First, S = Second; SD = Standard Deviation of the difference; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

Table G.8.

Data table corresponding to Figure 4.8: Difference of means of median perceived tension by Melody and Major chord Quality with 95% Confidence Intervals

Melody	Difference of means	SD	MOE	*r*
1 & 3	5.96	13.22	2.91	.716
1 & 5	7.82	10.99	2.41	.812
3 & 5	1.86	8.58	1.88	.532

Note. Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; SD = Standard Deviation of the difference; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

Table G.9.

Data table corresponding to Figure 4.9: Difference of means of median perceived tension by Melody and minor chord Quality with 95% Confidence Intervals

Melody	Difference of means	SD	MOE	*r*
1 & 3	4.62	10.51	2.31	.836
1 & 5	4.94	12.1	2.66	.781
3 & 5	0.33	11.2	2.46	.793

Note. Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; SD = Standard Deviation of the difference; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

Table G.10.

Data table corresponding to Figure 4.10: Difference of means of median perceived tension for the interaction of Melody and Expertise with 95% Confidence Intervals

Comparison	Difference of means	SD	MOE	*r*
1	7.98	28.18	3.54	.349
3	2.51	25.9	3.25	.405
5	5.52	24.84	3.12	.441

Note. Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; SD = Standard Deviation of the difference; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

Table G.11.

Data table corresponding to Figure 4.11: Difference of means of median perceived tension for the interaction of Inversion and Melody with 95% Confidence Intervals

Comparison	M	SD	MOE	*r*
R1 vs. R3	6.04	1.5	2.98	.659
R1 vs. R5	4.07	1.27	2.53	.761
R3 vs. R5	1.97	1.04	2.08	.783
F1 vs. F3	5.62	1.33	2.65	.743
F1 vs. F5	7.57	1.42	2.82	.694
F3 vs. F5	1.95	1.26	2.50	.688
S1 vs. S3	4.2	1.7	3.39	.578
S1 vs. S5	7.51	1.61	3.2	.609
S3 vs. S5	3.3	1.44	2.87	.626

Note. Inversion: R = Root, F = First, S = Second; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; SD = Standard Deviation of the difference; MOE = Margin of Error. Confidence Intervals (CIs) are twice the Margin of Error; *r* = Pearson Correlation Coefficient.

APPENDIX H: EXPLANATION AND EXAMPLE OF MEAN ROUGHNESS FOR F MINOR CHORD FORMATIONS USING VASSILAKIS AND FITZ'S *SRA* (*SPECTRAL AND ROUGHNESS ANALYSIS*)

SRA allows the actual sound files heard by participants in this study to be analysed. The programme analyses up to 50 frequencies (in decreasing amplitude magnitude) at each time point requested by the user, and calculates the roughness contribution of every pair of sine waves. For example, Table H.2 shows at 250ms, 415.32 Hz is the first frequency reported, and thus has the highest value for amplitude. *SRA* calculates the roughness contribution of 415.32 Hz paired with each of the other 49 frequencies. It does this for each of the 50 frequencies. Using this information, a roughness value is given for each sound file uploaded. Table H.1 reports the roughness values at 250ms intervals for the nine chord formations of f minor heard in this study.[435]

Table H.1.

Roughness values for f minor chord formations

ms	R1	R3	R5	F1	F3	F5	S1	S3	S5
250	58.15	68.71	73.59	64.49	66.36	75.00	63.92	66.38	65.66
500	50.15	90.77	74.91	46.01	83.47	71.84	78.15	89.04	71.37
750	40.91	76.71	58.59	40.75	85.18	60.97	70.60	73.25	63.02
1000	37.55	66.73	53.70	41.24	80.68	53.17	83.33	71.64	60.44
1250	35.31	77.16	52.88	36.21	81.19	57.06	85.37	73.07	53.43
1500	33.16	62.58	50.18	36.93	73.41	51.42	79.71	64.17	51.71
1750	31.87	64.13	52.77	34.02	75.60	47.55	81.46	57.96	49.14
2000	35.73	63.47	51.07	34.50	80.43	46.88	69.37	57.17	49.50
2250	33.26	64.70	49.94	33.72	69.43	49.17	70.87	59.29	44.49
2500	32.98	59.09	51.14	34.27	74.54	47.09	67.08	55.37	45.55
2750	32.00	64.36	50.13	35.52	75.64	52.15	70.34	58.05	41.32
3000	31.79	60.86	52.00	33.48	66.97	48.79	69.25	54.23	43.95
3250	34.80	61.09	52.16	33.79	73.45	51.57	63.78	57.36	41.80
3500	34.27	64.59	50.63	34.93	76.24	50.34	69.78	54.43	44.86
3750	33.55	63.27	54.69	34.10	69.72	51.33	65.80	58.10	41.26
(Median)	(37.03)	(64.48)	(52.16)	(34.93)	(75.6)	(51.42)	(70.34)	(58.1)	(49.14)

Note. Chord formations where Inversion: R = Root, F = First, and S = Second; Melody: 1 = Root of chord in top voice, 3 = third of chord in top voice, and 5 = fifth of chord in top voice; ms = milliseconds. Median values are bracketed as they represent only the median values for each formation of f minor, and not the overall median incorporating all chord formations for all 12 minor keys.

For the sound files used in this study, *SRA* calculated, at each time point, a median from 12-15 roughness values. For example, at 250ms the roughness value reported in Table H.2 is 68.71. This is obtained by sampling at

[435] *SRA* allows the user to determine the time interval at which the sound file is analysed. I initially chose the mid-point of 2000ms. Upon viewing variation in roughness values over time, I decided to ask *SRA* to analyse the sound files every 250ms, figuring the median of these values would be more representative of the roughness experienced by the participants than the single value at 2000ms.

275ms. Notice, in Table H.2, there are two rows recording time. The first row is the requested time for a roughness determination. The second row shows the time at which the roughness determination was made. *SRA* computes roughness within a 100ms window of the time requested.

Table H.2.

Time (milliseconds), frequency (Hertz), approximate pitch (C_4 is middle C), and roughness as determined by SRA for R3 (Root position_Melody 3) in f minor

Time	250ms	500ms	1500ms	3000ms	4000ms
Actual time	275ms	525ms	1550ms	3025ms	3975ms
1st frequency	415.32	415.80	174.96	416.46	175.03
	(≈A^b_4)	(≈A^b_4)	(≈F_3)	(≈A^b_4)	(≈F_3)
2nd frequency	523.66	523.76	350.43	350.52	262.63
	(≈C_5)	(≈C_5)	(≈F_4)	(≈F_4)	(≈C_4)
3rd frequency	174.35	349.84	262.36	524.10	416.54
	(≈F_3)	(≈F_4)	(≈C_4)	(≈C_5)	(≈A^b_4)
4th frequency	261.78	174.82	418.97	173.18	348.36
	(≈C_4)	(≈F_3)	(≈A^b_4)	(≈F_3)	(≈F_4)
5th frequency	832.28	261.74	833.72	833.07	699.85
	(≈A^b_5)	(≈C_4)	(≈A^b_5)	(≈A^b_5)	(≈F_5)
Roughness	68.71	90.77	62.58	60.86	65.12

Note. The actual pitches of the chord analysed by *SRA* were F_3-C_4-F_4-A^b_4. Frequencies listed above occur in order of decreasing amplitude as measured by *SRA*. For example, at time 1500ms, 174.96 had the highest amplitude, followed by 360.43, and so forth.

All 216 sound files used in this study were analysed for roughness using *SRA*. A median value was calculated for each chord formation. Table H.3 is an example of the roughness values, at 250ms intervals, for the chord formation Root position_Melody 3_minor chord Quality (R3n). For this chord formation, the chord with the lowest bass note (A^b_2) was a^b minor, and the chord with the highest bass note (G_3) was g minor.

Table H.3.

Roughness values for R3n reported at 250ms intervals

R3n	ms	c	$c^{\#}$	d	e^{b}	e	f	$f^{\#}$	g	a^{b}	a	b^{b}	b
	250	69.82	64.49	60.37	62.31	64.36	68.71	72.84	71.93	61.75	65.47	70.33	73.44
	500	95.27	97.69	82.95	88.09	98.57	90.77	90.67	72.64	65.81	68.86	87.72	88.82
	750	98.05	99.99	88.45	88.83	85.23	76.71	66.37	61.16	62.72	68.02	89.62	95.32
	1000	101.09	96.86	90.30	86.32	77.92	66.73	66.76	60.52	64.25	62.59	89.88	104.19
	1250	86.46	92.40	87.70	86.44	82.14	77.16	64.37	62.69	63.51	67.18	87.52	84.67
	1500	85.23	84.46	86.96	77.89	78.72	62.58	63.54	61.78	59.94	57.59	90.67	87.52
	1750	82.07	76.44	70.73	74.36	63.64	64.13	66.22	57.73	61.23	60.97	72.99	89.10
	2000	75.73	73.84	71.15	65.51	64.42	63.47	68.39	57.99	58.86	54.86	81.67	80.10
	2250	73.92	75.41	76.47	66.13	68.68	64.70	61.84	61.75	57.45	59.90	80.34	81.04
	2500	74.18	67.74	72.05	71.91	66.34	59.09	63.32	58.87	58.81	61.62	83.24	76.36
	2750	72.36	73.85	70.50	68.74	69.48	64.36	63.35	61.67	60.35	57.50	75.45	77.02
	3000	75.94	72.41	74.31	68.53	66.00	60.86	68.74	59.22	57.39	56.01	74.65	81.28
	3250	74.91	78.08	76.14	68.69	68.14	61.09	62.58	63.80	60.75	59.84	79.32	75.91
	3500	73.41	71.48	72.94	70.81	71.40	64.59	64.28	60.67	59.72	61.32	78.48	81.25
	3750	69.17	72.53	74.07	68.86	69.58	63.27	66.36	58.55	63.25	58.54	78.48	78.65
MEAN	72.38	80.51	79.84	77.01	74.23	72.97	67.22	67.31	62.07	61.05	60.81	81.36	83.64
MEDIAN	69.56	75.57	74.86	73.50	69.53	66.53	64.48	63.34	60.95	60.86	69.59	81.15	81.25

Note. R3n = Root position, third of chord in soprano, minor keys; ms = milliseconds; c, $c^{\#}$, ... b are the 12 minor keys.

APPENDIX I: COOK'S *SEEING HARMONY* (*SH*) PROGRAMME FOR MEASURING TENSION, DISSONANCE, AND INSTABILITY IN FOUR-NOTE CHORDS

Instability of chords results from Dissonance and Tension. Values for Dissonance (intervallic effects) and Tension (chordal effects) are determined by the partials of each tone, the amplitude of each, and the size of the intervals between successive tones.[436] Cook includes a Tension value, as "the summation of interval consonance does not accurately predict triadic sonority."[437] According to Cook, there is empirical evidence to support the role interval consonance/dissonance in the perception of sensory dissonance in dyads, but not in triads or harmonies of more than two tones. As shown in Equation 1, the Dissonance and Tension are not weighted equally in his theory. Dissonance due to interval effects are weighted more than is Tension due to triadic (or, in the case of this study, tetrad) effects.

Instability = **D**issonance + (≈.2)**T**ension (Eq. 1)

For his application of the *Seeing Harmony* (*SH*) program, Cook used triads in close position. He calculated, and summed, Interval Dissonance for each pair of partials. In this study, participants heard four-note chords. Using R1M, a Root position_Melody 1_C Major chord (C_3-G_3-E_4-C_5) as an example, Interval Dissonance is calculated, and summed, for $F_0(C_3\text{-}G_3)$, $F_0(G_3\text{-}E_4)$, $F_0(E_4\text{-}C_5)$, $F_1(C_3\text{-}G_3)$, $F_1(G_3\text{-}E_4)$, $F_0(E_4\text{-}C_5)$, ... $F_x(C_3\text{-}G_3)$, $F_x(G_3\text{-}E_4)$, $F_x(E_4\text{-}C_5)$.[438] Equation 2 is used to calculate of Dissonance for each interval.

D = $v \text{ X } \beta_3[\exp(-\beta_1 x) - \exp(-\beta_2 x)]$ (Eq. 2)[439]

Tension, too, is based on the distance between the successive intervals at each frequency level, i.e., F_0, F_1, ... F_x. This equation, however, considers the overall difference in distance between all successive tones at the same frequency level. Cook believes lack of intervallic symmetry results in less (triadic) **T**ension. An augmented triad (C-E-G$^{\#}$-C-E-G$^{\#}$) is perceived as tenser than a minor triad (C-E^{b}-G-C-E^{b}-G) due to the symmetry of the intervals—(semitones: 4, 4, 4, 4, 4) in the case of the augmented triad, and (semitones: 3, 4, 5, 3, 4) in the case of the minor triad. Put another way, less Tension is experienced when the difference in semitone distance between successive tones does not equal zero. This is the case with the c minor triad where the distance from the root to the third—3 semitones—minus the distance from the third to the fifth—4 semitones— equals -1. The distance from the root to the third of the augmented triad—4 semitones— is the same as the distance from the third to the fifth—4 semitones—equals 0. Thus, the minor triad is perceived as less tense than is the augmented triad. While, it is unclear how the theory of symmetry may be applied to chords of more than 3 notes, or chords not in close position, equation 3 can be modified to accommodate such chords.

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436 The fundamental, F_0, is the first partial. The first overtone, F_1, is the second partial, and so forth.

437 Norman Cook, "Harmony Perception: Harmoniousness in More than the Sum of Interval Consonance," *Music Perception* (2009) Vol. 27, no. 1, 28.

438 F_0 is the fundamental frequency of a tone. F_1 is the first partial of a tone. $F_0(C_3)$ is 130.8 Hz and $F_1(C_3) = F_0(C_4) =$ 261.6 Hz.

439 **D**issonance = product of the relative amplitudes of the partials of the two tones (v) X 4.0 (β_3) [interval of maximal dissonance ($\beta_1 = -.8$; just less than a semitone) - steepness of fall from maximal dissonance ($\beta_2 = -1.6$)] and x is the size of the interval (log f_2/f_1). Cook (2009), 27.

$$\mathbf{T} = v \times \exp\left[-\left(\frac{y - x}{\alpha}\right)^2\right] \qquad \text{(Eq. 3)}$$ [440]

On his website (http://www.res.kutc.kansai-u.ac.jp/~cook/05%20harmony.html) Cook posted a programme to calculate **D**issonance (**D**) due to interval effects and **T**ension (**T**) due to chordal effects, resulting in an **I**nstability value (**I**). My first attempt to use this programme resulted in identical values for **D**, **T**, and **I**, regardless of Inversion, Melody, and/or chord Quality. I contacted Dr. Cook through email and he rewrote the programme.[441] It is this new version that was used to analyse the chords used in this study. It allows the user to indicate how many tones are in the chord, how many partials to include, whether to input tones by number or frequency, and identify the rate of amplitude decay.

Some questions were easy to answer. How many chord tones? Answer: 4. How many partials? Answer: 5.[442] The next question concerns inputting chord tones and requires extended explanation. I will proceed with the final question and return to the process of inputting tones. Cook gives four choices for rate of amplitude decay. The default is equal (1.0). The other choices are 1/n, Sethares ($.88^n$), and Kameoka (.5, .8, 1, .6). I chose 1/n, where n = number of partial, as this is the value Cook (2009) uses.

Users are given the choice of inputting pitches by number, where $C_4 = 0$, $C^\#_4 = 1$, et cetera, or by frequency, where $C_4 = 261.6$, $C^\#_4 = 277.18$, et cetera. I chose to input using frequencies, as the default for tone 1 was middle C (C_4). With tone 1 set as $C_4 = 0$, I could not input tone 2 as -3 (A_3). With tone 1 set as $C_4 = 261.6$, I could input tone 2 as 220 Hz (A_3). In this way, I was able to include most chords containing C_4 as root, third, or fifth. Unlike with Vassilakis's *Spectral and Roughness Analysis*, I was not able to analyse all 216 chord formations. Because of the default for tone 1, and the restriction of range (F_2 to G_5) of chord formations used in the study, only the Major keys of C, F and A^b, and minor keys of c, f, and a could be used. As Table I.1 shows, the result was an inconsistent number of samples for each chord formation totalling 53.

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[440] **T**ension = product of the relative amplitudes of the partials of the three partials (v) , α (≈0.6) steepness of fall from maximal tension, $x = \log(f_2/f_1)$ lower interval of triad, $y = \log(f_3/f_2)$ upper interval of triad and frequency (Hertz) $f_1 < f_2 < f_3$. Cook (2009), 28.

[441] I received the revised programme September 15, 2015.

[442] I followed Cook's suggestion, "musical sounds usually consider the first 4-5 partials." Cook (2009), 25.

Table I.1.

Chord formations and keys analysed using Cooks Seeing Harmony-tetrad version

	Chord formation								
Key	R1	R3	R5	F1	F3	F5	S1	S3	S5
C		✓	✓	✓	✓	✓	✓	✓	✓
F	✓	✓	✓	✓	✓	✓✓	✓✓	✓	
A^b	✓	✓	✓		✓✓	✓	✓		✓
c		✓	✓	✓	✓	✓	✓	✓	✓
f	✓	✓	✓	✓	✓	✓✓	✓✓	✓	
a	✓	✓	✓	✓	✓✓	✓	✓		✓
Total	4	6	6	5	8	8	8	4	4

Note. Inversion where Root = Root position, F = First, and S = Second; Melody where 1 = root of chord in soprano, 3 = third of chord in soprano, and 5 = fifth of chord in soprano; upper case key is Major and lower case is minor.

Four examples of tones entered into *SH* for analysis are found in Table I.2. The first, R1 in F, is acceptable as it falls within the pitch range used in this study. The same cannot be said for S3 in A^b. Because the default for Tone 1 is C_4, the bass note must be E^b_2. However, E^b_2 is out of pitch range. The actual pitches used for S3 in A^b in this study were E^b_3- E^b_4- A^b_4- C_5. They could not be entered into *SH* as the default C_4 is not among the pitches. A different situation occurs with F3 in a minor. Here, there were two possible configurations, both using C_4. Both were entered into *SH* to analyse as many samples as possible.

Table I.2.

Examples of chord formations and tones entered into "Seeing Harmony."

Key	Chord formation	Tone 1 (default)	Tone 2	Tone 3	Tone 4
F	R1: F-C-A-F	C_4	F_3	A_4	F_5
a	F3: C-E-A-C	C_4	C_3	E_3	A_3
a	F3: C-E-A-C	C_4	E_4	A_4	E_5
A^b	S3: E^b-E^b-A^b-C	C_4	E^b_2	E^b_3	A^b_3

Note. Key: Upper case = Major, lower case = minor; Inversion: R = Root position, F = First Inversion, S = Second Inversion; Melody: 1 = root of chord in soprano, 3 = third of chord in soprano. For ease of reading, tones are represented by letters and subscripts indicating register where C_4 is middle C. Tone frequencies, in Hertz, were actually entered into the program.

Table I.3.

Data for Figure 5.11 Mean Instability values and mean of medians perceived tension for all Major Quality and minor Quality chord formations

Quality	Instability	Perceived Tension
Major	9.76	27.07
minor	9.8	44.99

Table I.4.

Data for Figure 5.13 Mean Instability and mean of medians perceived tension by Inversion

Inversion	Instability	Perceived Tension
Root	10.57	36.99
First	7.89	42.22
Second	10.88	43.93

Table I.5.

Data for Figure 5.14 The inverse of Instability and mean of medians perceived tension by Inversion

Inversion	1/Instability (x100)	Perceived Tension
Root	9.46	36.99
First	12.67	42.22
Second	9.19	43.92

Table I.6.

Data for Figure 5.15 Mean Instability and mean of medians perceived tension due to Melody

Melody	Instability	Perceived Tension
1	10.27	44.93
3	8.72	39.65
5	10.34	38.55

Note. 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice.

APPENDIX J: TABLES FOR FIGURES 6.2 TO 6.5[443] AND RATIO TO MINOR

Tables J.1 to J.3 correspond to the data plotted in Figures 6.2 to 6.5. The first column in the tables, Event, refers to the prolongation reduction in Figure 6.1 (replicated here as Figure J.1) and is hierarchical, not sequential, in nature. For this reason, you will see entries like 6→5 in the column labelled 'Event.' By looking at the hierarchical branching in Figure 6.1, you will see left branching Event 5 inherits tension from its superordinate Event 6.

Lerdahl's *Surface Tension Rule* includes a column for nonchord tones not included in these examples, as there are no nonchord tones in Figure 6.1. Due to the results of this study, the column 'Quality' has been added to the Surface tension category. The column 'Total' has been added to facilitate the creation of Figures 6.2 and 6.3.

Under the heading 'Pitch space' are the values for regional distance (i), chordal distance (j), and pitch class space (k). Regional distance is determined by the number of steps around the regional circle-of-fifths (Figure 1.10). Chordal distance is determined by the number of steps around the chordal circle-of-fifths (Figure 1.5). The distance in pitch class space is determined by the number of distinct pitches in the basic space (Figure 1.3) in the second chord compared with the first chord.

'Local tension' is the sum of 'surface tension' and 'pitch space.' 'Inherited tension' is the pitch space tension added to subordinate chords by superordinate chords. For example, from Figure 6.1 we know Event 4 is subordinate to Events 5 and 6. Thus Event 4 inherits 2 ($i = 1 + k = 1$) from Event 5 and 5 ($j = 1 + k = 4$) from Event 6. 'Global tension' is the sum of 'Local' and 'Inherited' tension.

[443] This Figure is based on the prolongational reduction (Figure 4.5, p. 147) and hierarchical tension (Figure 4.11, p. 152) taken from Lerdahl (2001). Any diminished and seventh chords were changed, as they were not included in the stimuli used in this study. Thus, Event 4 was changed from vii^{o6} to V^6_4, Event 7 from V^4_2 to V^6_4, Event 9 from V^4_2 to V, Event 11 from ii^7 to ii^6, and Event 12 from V^7 to V. The changes to Lerdahl's original figure also resulted in several changes to the various melody lines and consecutive Perfect 5ths between the alto and soprano of events 10 and 11.

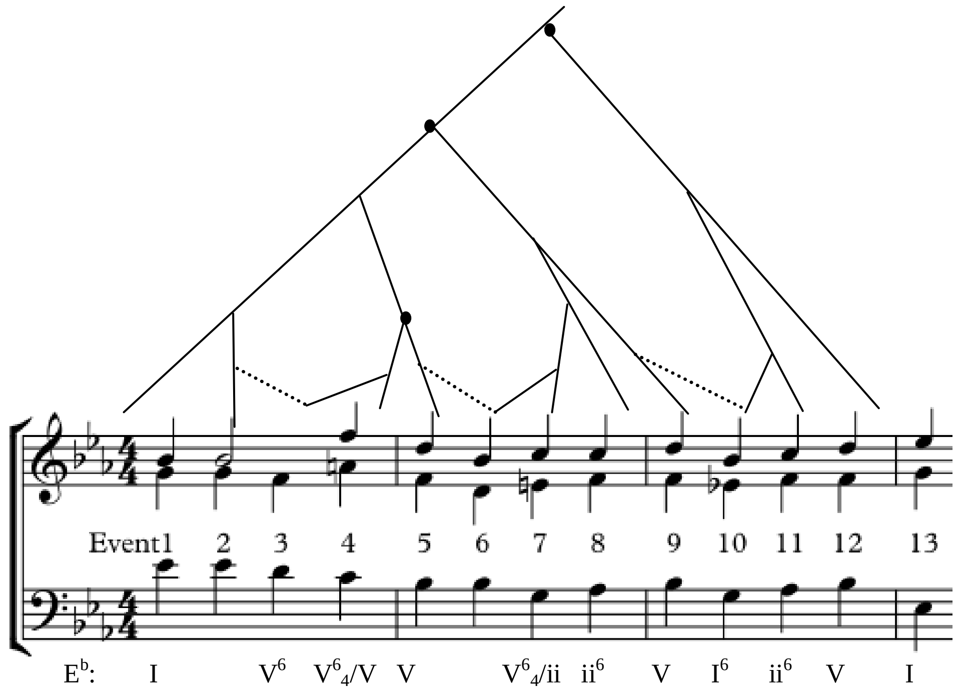

Figure J.1. Modified Prolongational reduction and hierarchical tension taken from Lerdahl (2001), Figure 4.5, 147. Filled circles indicate weak prolongation. Dashed lines indicate sequential branching.

Table J.1.

Modified Figure 4.11 from Lerdahl (2001), 151 corresponding to Figures 6.2 to 6.5

		Surface tension				Pitch space			Tension	
Event	Inversion	Melody	Quality	TOTAL	*i*	*j*	*k*	Local	Inherited	Global
1→1	0	1	0	1	0	0	0	1	0	1
1→2	0	1	0	1	0	0	0	1	0	1
1→3	2	0	0	2	0	1	4	7	0	7
5→4	2	1	0	3	0	1	5	9	7	16
6→5	0	1	0	1	1	0	1	3	5	8
1→6	2	0	0	2	0	1	4	7	0	7
8→7	2	0	0	2	0	1	4	7	12	19
9→8	2	1	0	3	1	1	5	10	5	15
10→9	0	1	0	1	0	1	4	6	0	6
1→10	2	1	0	3	0	0	0	3	0	3
12→11	2	1	0	3	0	1	4	8	5	13
13→12	0	1	0	1	0	1	4	6	0	6
1→13	0	0	0	0	0	0	0	0	0	0

Table J.2.

Ratio to Major Surface Tension values substituted for Lerdahl's Surface Tension values (Table J.1) corresponding to Figures 6.2 to 6.5

		Surface tension				Pitch space			Tension	
Event	Inversion	Melody	Quality	TOTAL	*i*	*j*	*k*	Local	Inherited	Global
1→1	1.37	1.42	1	3.79	0	0	0	3.79	0	3.79
1→2	1.37	1.42	1	3.79	0	0	0	3.79	0	3.79
1→3	1.56	1.66	1	4.22	0	1	4	9.22	0	9.22
5→4	1.62	1.66	1	4.28	0	1	5	10.28	7	17.28
6→5	1.37	1.46	1	3.83	1	0	1	5.83	5	10.83
1→6	1.37	1.66	1	4.03	0	1	4	9.03	0	9.03
8→7	1.62	1.66	1	4.28	0	1	4	9.28	12	21.28
9→8	1.56	1.42	2.03	5.01	1	1	5	12.01	5	17.01
10→9	1.37	1.46	1	3.83	0	1	4	8.83	0	8.83
1→10	1.56	1.66	1	4.22	0	0	0	4.22	0	4.22
12→11	1.56	1.42	2.03	5.01	0	1	4	10.01	5	15.01
13→12	1.37	1.46	1	3.83	0	1	4	8.83	0	8.83
1→13	1.37	1.66	1	4.03	0	0	0	4.03	0	4.03

Table J.3.

Regression Surface Tension values substituted for Lerdahl's Surface Tension values (Table J.1) corresponding to Figures 6.2 to 6.5

		Surface tension				Pitch space			Tension	
Event	Inversion	Melody	Quality	TOTAL	*i*	*j*	*k*	Local	Inherited	Global
1→1	0.643	3.947	0.246	4.84	0	0	0	4.84	0	4.84
1→2	0.643	3.947	0.246	4.84	0	0	0	4.84	0	4.84
1→3	7.451	5.741	0.246	13.44	0	1	4	18.44	0	18.44
5→4	9.345	5.741	0.246	15.33	0	1	5	21.33	7	28.33
6→5	0.643	4.512	0.246	5.40	1	0	1	7.40	5	12.40
1→6	0.643	5.741	0.246	6.63	0	1	4	11.63	0	11.63
8→7	9.345	5.741	0.246	15.33	0	1	4	20.33	12	32.33
9→8	7.451	3.947	19.75	31.15	1	1	5	38.15	5	43.15
10→9	0.643	4.512	0.246	5.40	0	1	4	10.40	0	10.40
1→10	7.451	5.741	0.246	13.44	0	0	0	13.44	0	13.44
12→11	7.451	3.947	19.75	31.15	0	1	4	36.15	5	41.15
13→12	0.643	4.512	0.246	5.40	0	1	4	10.40	0	10.40
1→13	0.643	5.741	0.246	6.63	0	0	0	6.63	0	6.63

Table J.4.

Portion Surface Tension values substituted for Lerdahl's Surface Tension values (Table J.1) corresponding to Figures 6.2 to 6.5

		Surface tension				Pitch space			Tension	
Event	Inversion	Melody	Quality	TOTAL	*i*	*j*	*k*	Local	Inherited	Global
1→1	0.3	0.31	0.33	0.94	0	0	0	0.94	0	0.94
1→2	0.3	0.31	0.33	0.94	0	0	0	0.94	0	0.94
1→3	0.34	0.36	0.33	1.03	0	1	4	6.03	0	6.03
5→4	0.36	0.36	0.33	1.05	0	1	5	7.05	7	14.05
6→5	0.3	0.32	0.33	0.95	1	0	1	2.95	5	7.95
1→6	0.3	0.36	0.33	0.99	0	1	4	5.99	0	5.99
8→7	0.36	0.36	0.33	1.05	0	1	4	6.05	12	18.05
9→8	0.34	0.31	0.67	1.32	1	1	5	8.32	5	13.32
10→9	0.3	0.32	0.33	0.95	0	1	4	5.95	0	5.95
1→10	0.34	0.31	0.33	0.98	0	0	0	0.98	0	0.98
12→11	0.34	0.31	0.67	1.32	0	1	4	6.32	5	11.32
13→12	0.3	0.32	0.33	0.95	0	1	4	5.95	0	5.95
1→13	0.3	0.36	0.33	0.99	0	0	0	0.99	0	0.99

Table J.5.

Mean of medians perceived tension of all levels compared with mean of medians perceived tension of Ratio to minor chord Quality, Ratio to Major chord Quality, Portion, and Rank-Final

Factor	Level	Mean of medians	Ratio(minor)	Ratio(Major)	Portion	Rank-Final
Inversion	Root	36.99	.67	1.37	.3	2
	First	42.22	.77	1.56	.34	4
	Second	43.93	.8	1.62	.36	5
Melody	1	44.93	.82	1.66	.36	5
	3	39.65	.72	1.46	.32	3
	5	38.55	.7	1.42	.31	3
Quality	Major	27.07	.49	1	.33	1
	minor	55.02	1	2.03	.67	6

Note. Inversion: Root = Root of chord in the bass, First = 3rd of chord in bass, Second = 5th of chord in bass; Melody: 1 = root of chord in top voice, 3 = third of chord in top voice, 5 = fifth of chord in top voice; Ratio (minor) = Level Mean of medians/minor Mean of medians; Ratio (Major) = Level Mean of medians/Major Mean of medians from Table 6.3; Rank-Final from Table 6.2.

Table J.6.

Ratio to minor chord Quality and Portion Surface Tension values substituted for Lerdahl's Surface Tension values (Table J.5) corresponding to Figures J.2 and J.3.

		Surface tension					Pitch space			Tension		
Event	Inversion	Melody	Quality	TOTAL	Portion	*i*	*j*	*k*	Local	Inherited	Global	Portion
1→1	.67	.7	.49	1.86	0.94	0	0	0	1.86	0	1.86	0.94
1→2	.67	.7	.49	1.86	0.94	0	0	0	1.86	0	1.86	0.94
1→3	.77	.82	.49	2.08	1.03	0	1	4	7.08	0	7.08	6.03
5→4	.8	.82	.49	2.11	1.05	0	1	5	8.11	7	15.11	14.05
6→5	.67	.72	.49	1.88	0.95	1	0	1	3.88	5	8.88	7.95
1→6	.67	.82	.49	1.98	0.99	0	1	4	6.98	0	6.98	5.99
8→7	.8	.82	.49	2.11	1.05	0	1	4	7.11	12	19.11	18.05
9→8	.77	.7	1	2.47	1.32	1	1	5	9.47	5	14.47	13.32
10→9	.67	.72	.49	2.08	0.95	0	1	4	7.08	0	7.08	5.95
1→10	.77	.82	.49	2.08	0.98	0	0	0	2.08	0	2.08	0.98
12→11	.77	.7	1	2.47	1.32	0	1	4	7.47	5	12.47	11.32
13→12	.67	.72	.49	1.88	0.95	0	1	4	6.88	0	6.88	5.95
1→13	.67	.82	.49	1.98	0.99	0	0	0	1.98	0	1.98	0.99

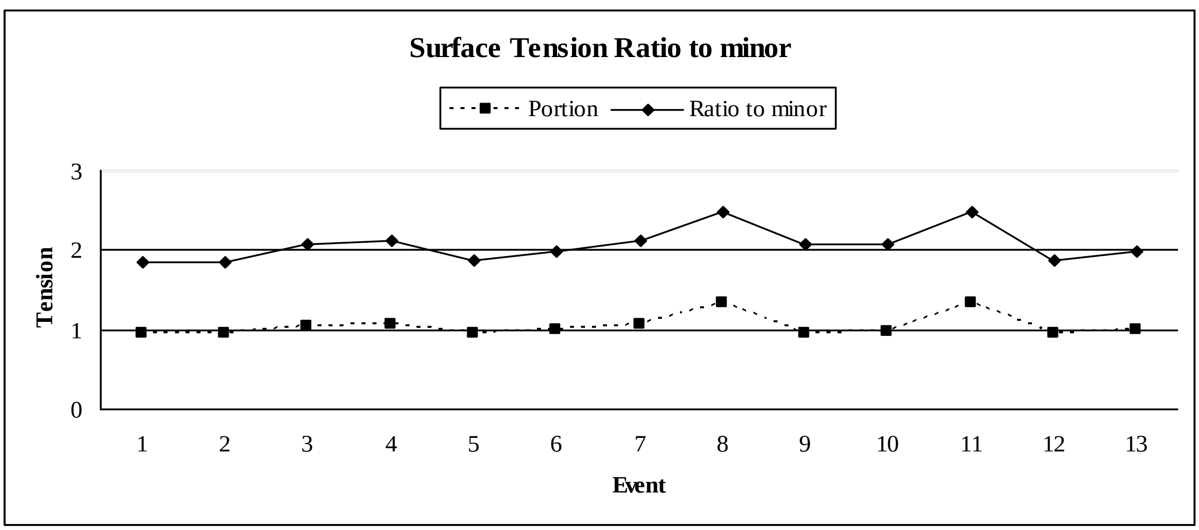

Figure J.2. Values for Surface tension (Inversion, Melody, and chord Quality) by event, as determined by Ratio to minor chord Quality and Portion.

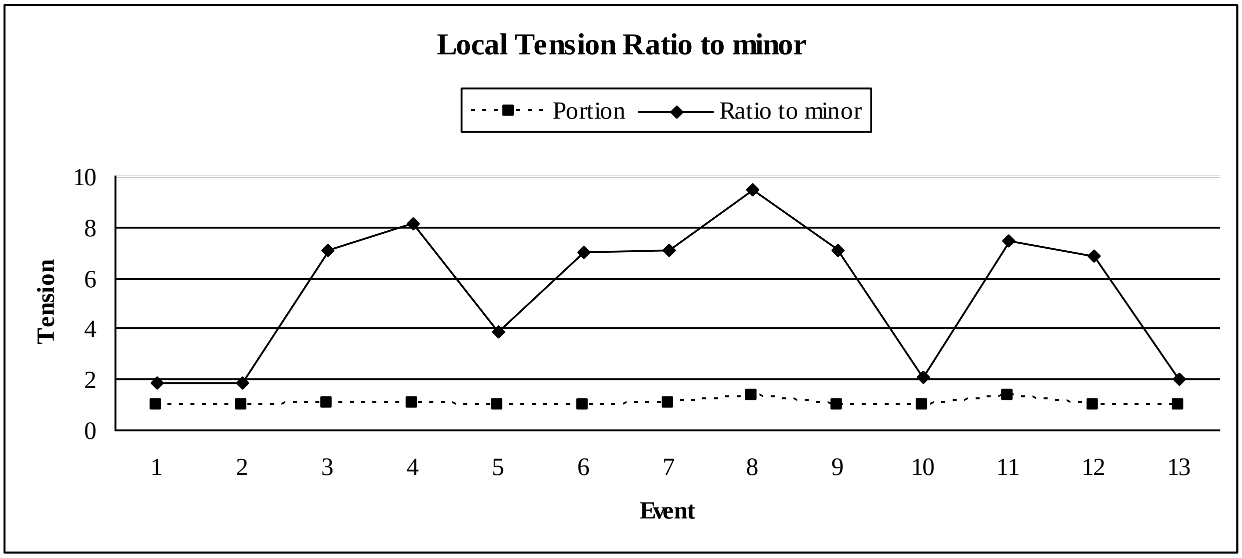

Figure J.3. Local tension calculated using tension added values obtained from Ratio to minor chord Quality and Portion.

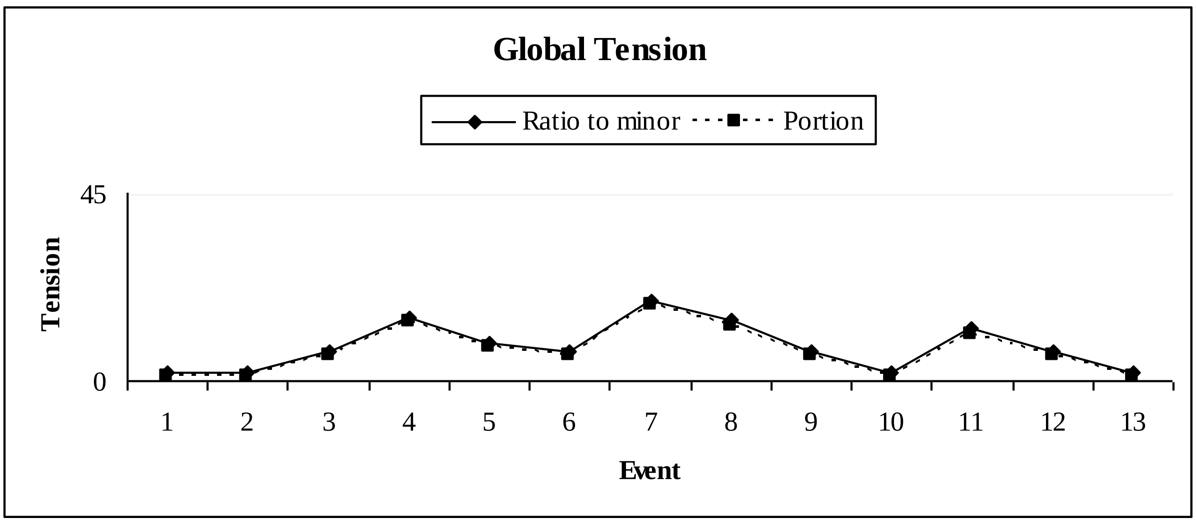

Figure J.4. Global tension calculated using tension added values obtained from Ratio to minor chord Quality and Portion.

While values obtained using Ratio to minor chord Quality produces some extreme values at the level of local tension, we can see from Figure J.4, there is little difference between global tension as determined by Ratio to minor chord Quality and by Portion. Surface tension, as determined by Portion, provides lower tension added values and thus, lower local (Figure J.3) and global tension (Figure J.4) values. Figure J.5 shows the impact of surface tension values determined by Ratio to minor chord Quality upon global tension. The influence, like the surface tension values determined by Portion, is small. As discussed in chapter 6, this is desirable. Tension added values due to surface dissonance should not overwhelm values due to harmonic and melodic features of the music.

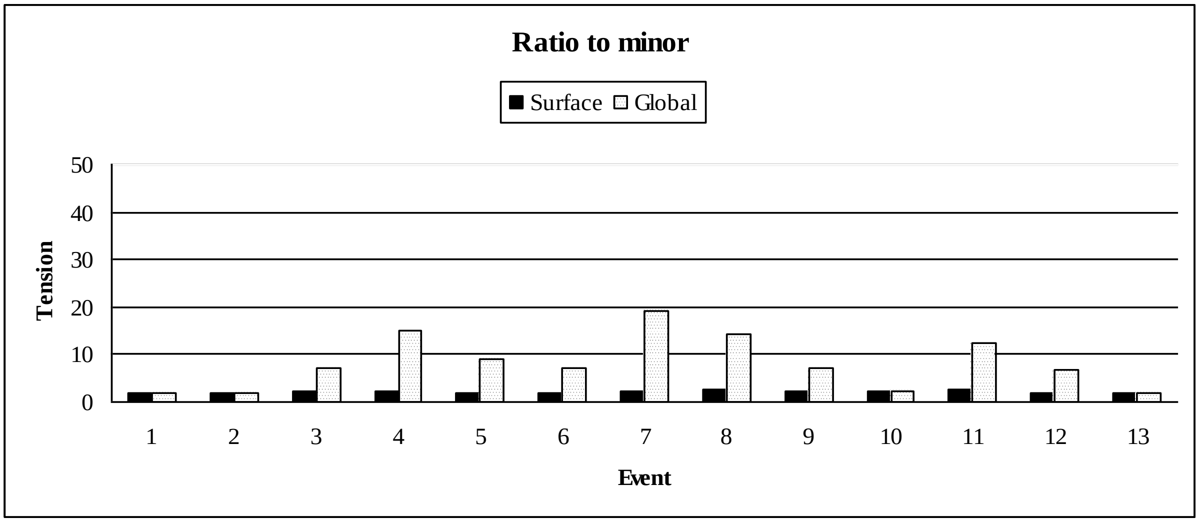

Figure J.5. Surface and global tension calculated using values suggested by Lerdahl's model using Ratio to minor chord Quality tension added values instead of those suggested by *STR*.

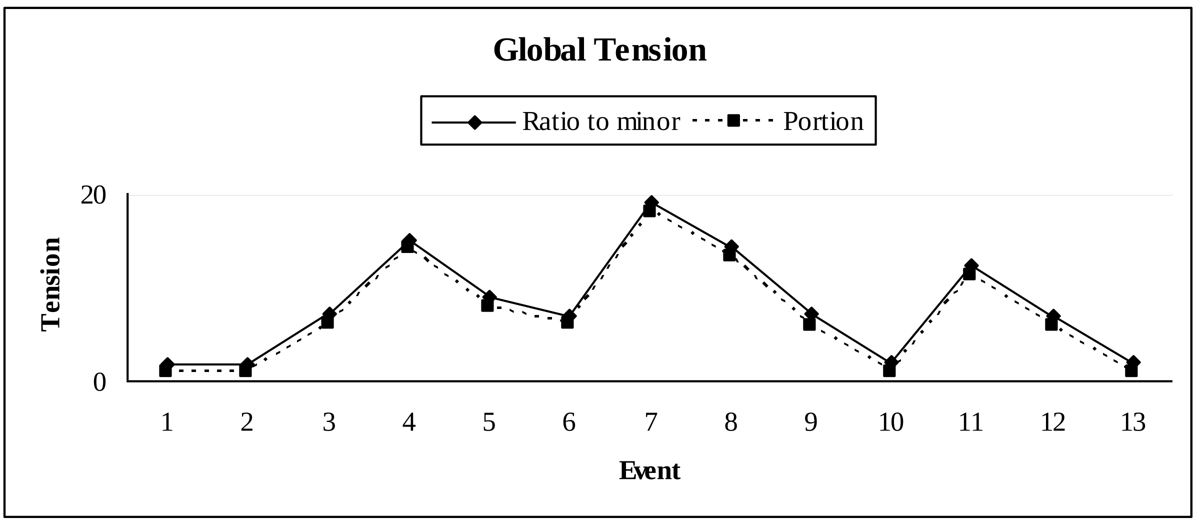

Figure J.6. Global tension calculated using tension added values obtained from Ratio to minor chord Quality and Portion using smaller scale for y-axis.

Figure J.6 is an enlargement of Figure J.4 where we can see more clearly the global tension values as determined by Portion are smaller than those determined by Ratio to minor chord Quality. Unlike global tension calculated using Ratio to Major chord Quality, Lerdahl's *Surface Tension Rule*, and Regression, global tension calculated using by tension added values determined by Ratio to minor chord Quality follow the same contour and hold close to the preferred values determined by Portion.[444] We see the extreme values found at events 4, 7, 8, 10, and 11 when applying tension added values of Ratio to Major chord Quality, Lerdahl's *Surface Tension Rule*, and

[444] Ratio to minor chord Quality is compared to Portion as Portion returned tension added values that did not overshadow tension due to harmonic and melodic features of the music. Chapter 6 explains why, of the possible methods for obtaining tension added values due to surface tension—Ranking, Lerdahl's *Surface Tension Rule*, Ratio to Major chord Quality, Regression, and Portion— Portion was chosen.

Regression (Figures 6.2 and 6.3) are not present. This is because the impact of minor chord Quality (19.75 for Regression and 2.03 for Ratio to Major chord Quality) on events 8 and 11 (ii^6) is reduced to .67 for Portion and 1 for Ratio to minor chord Quality. The impact of Second Inversion (9.345 for Regression, 2 for *STR*, and 1.62 for Ratio to Major chord Quality) on events 4 and 7 has been reduced to .36 for Portion and .8 for Ratio to minor chord Quality. The impact of First Inversion (7.451 for Regression, 1 for *STR*, and 1.62 for Ratio to Major chord Quality) on events 8 and 11 has been reduced to .34 for Portion and .77 for Ratio to minor chord Quality. While tension added values, due to surface tension, determined by Ratio to minor chord Quality are less likely to eclipse perceived tension due to harmonic and melodic features, tension added values determined by Portion are still preferred. These lower tension added values still acknowledge the influence of Inversion, Melody, and chord Quality upon tension perceived by listeners but do so without overshadowing perceived tension due to harmonic and melodic features of the music.[445]

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[445] Other musical features such as tempo and instrumentation also affect listeners' perception of tension but are not part of Lerdahl's model of tonal pitch space.

APPENDIX K: DETERMINING MUSICAL EXPERTISE

With Western tonal music heard nearly everywhere you go in Southern Ontario, it becomes difficult to draw strict boundaries between levels of musical expertise for experiments such as presented in this study. People hear music while driving a car, while on the bus, while working out at the gym, while watching television, a movie, playing a video game, while shopping for clothes and groceries. Expertise, as defined in this study, is not concerned only with amount of education and level of skill demonstrated through performance on a musical instrument. Rather, the degree of expertise I am trying to determine in this study also includes exposure to Western tonal music. The two factors from Lerdahl's *Surface Tension Rule* tested in this study (perceived tension due to Inversion and Melody), plus the factor not recognised by Lerdahl's *Surface Tension Rule* but revealed in this study (perceived tension due to chord Quality), appear to be related more to exposure to Western tonal music than level of music education and/or level of proficiency on an instrument.

Identifying levels of musical expertise in music perception research has been unsystematic, making it difficult to compare results across studies. In response to this predicament, Joy Ollen created the Ollen Musical Sophistication Index (OMSI) with which she attempts to quantify what this study labels expertise and she calls musical sophistication. Ollen's definition of musical sophistication is based on Hallam, Susan, and Vanessa Prince. "Conceptions of Musical Ability." *Research Studies in Music Education* Vol. 20 (2003): 2-22. "Hallam and Prince presented a very rich, complex picture of what musical ability encompasses: aural skills, receptive responses such as being able to listen to, understand, appreciate and evaluate music and musical performances, generative skills such as being able to play, sing, read, compose ad improvise music individually or as part of an ensemble with technical and artistic skill, integration of many skills, personal qualities such as motivation and commitment, and a progressive development of both innate and learned abilities." [446]

Among the steps taken to arrive at the best series of questions to ask participants, Ollen created 30 questions based on 29 indicators of musical sophistication. Through regression analysis she determined the 10 most powerful indicators of musical sophistication. The questions in Table K.2 reflect this analysis. Table K.1 lists the questions asked in the present study.

The questions in Tables K.1 and K. 2 attempt to gauge expertise by evaluating participants' level of musical education and exposure to Western tonal music. Ollen's questions are more specific enabling her to obtain clearer distinctions between participants, and to quantify these distinctions. Table K.3 shows the scoring template Ollen created based upon results obtained through regression analysis of data collected during her study. Table K.4 is an application of OMSI to data obtained from two participants in the present study.[447] Based on the criteria described in the method section of this paper, one participant was identified as Novice and one as Expert. [448]

[446] Joy Ollen, "A Criterion-related Validity Test of Selected Indicators of Musical Sophistication Using Expert Ratings," PhD diss., Ohio State University (2006), 4.
https://etd.ohiolink.edu/!etd.send_file?accession=osu1161705351&disposition=inline

[447] This is new data obtained after the completion of the present study for the purpose of applying OMSI to two participants (one Novice and one Expert).

[448] Novices are defined as pursuing an undergraduate degree in music, or with less than twenty years performing experience and pursuing music as a hobby. Experts are defined as having completed an undergraduate degree in music, and/or graduate music degree, and/or with more than twenty years performing experience.

Using Ollen's equation below, results in a number (Ollen calls this "logit") quantifying participants' musical sophistication. For ease of interpretation, the resulting number can be expressed as "the predicted probability (*P*) of being classified as more musically sophisticated, using the equation: $P = e^{logit}/(1 + e^{logit})$."[449] Ollen interprets a *P* greater than .5 as representing a participant whose likelihood of being more musically sophisticated is greater than 50%; *P* less than .5 as representing a participant whose likelihood of being less musically sophisticated is greater than 50%.[450]

logit (musical sophistication) = constant (-3.513) + $RC_{6\&7}$ (completed college-level course-work) + RC_1 (age today) + RC_2 (age starting musical studies) + RC_3 (years of private lessons) + RC_4 (years of regular practice) + RC_5 (current practice amount) + RC_8 (composing experience) + RC_9 (concert attendance) + RC_{10} (self-ranking)[451]

Table K.1.

Pre-and Post-test questions from present study

Pre-test	How old are you?
Post-test	
1	What is your primary instrument?
2	How many years of training on this instrument?
3	What Royal Conservatory of Music level have you obtained?
4	What level of musical training at university have you completed?
5	Do you Do you play a second instrument?
6	What Royal Conservatory of Music level have you obtained?
7	What level of musical training at university have you completed?
8	Do you have perfect or absolute pitch?
9	How many hours per week are actively engaged in listening to music (where actively means practicing, teaching, attending a concert, any activity where music has your full attention)?
10	How many hours per week are you passively listening to music (meaning music is in the background while you are engaged in other activities)?

[449] Ollen, 121.
[450] Ollen, 121.
[451] Ollen, 121. RC means Regression Coefficient the exact values can be found in Table K.3. The subscript number refers to the question number in Table K.2. All the necessary information is present, but I have simplified Ollen's example.

Table K.2.

Ten questions from Ollen Musical Sophistication Index[452, 453]

1	How old are you today?
2	At what age did you begin sustained musical activity (regular music lessons or daily musical practice lasting for at lease 3 consecutive years?
3	How many years of private music lessons have you had?
4	For how many years have you engaged in regular, daily practice of a musical instrument or singing?
5	Which category comes nearest to the amount of time you currently spend practicing an instrument? (rarely=0, 1 hour per month=1, 1 hour per week=2, 15 minutes per day=3, 1 hour per day=4, more than 2 hours per day=5)
6	Have you ever enrolled in any music courses offered at college or university?
7	How much college-level coursework in music have you completed? (none=1, 1-2 non-music major=2, 3 or full-time Bachelor more non-music major=3, introductory courses for music programme=4, 1 year of Music=5, 2years=6, 3 years or more=7, completed Bachelor of Music=8, one or more graduate level=9)
8	Which option best describes your experience at composing music? (never=0, bits and pieces but nothing complete=1, one or more but not performed=2, class assignments=3. performed for local audience=4, composed for national-major concert-known performer-broadly distributed recording=5)
9	How many live concerts attended in past 12 months? (none=0, 1-4=1, 5-8=2, 9-12=3, 13+=4)
10	Which title best describes you? (non-musician=0, music-loving non-musician=1, amateur musician=2, serious amateur=3, semi-professional=4, professional=5)

[452] Joy Ollen, (2006), 237-239 (paraphrased) I have abbreviated the information Ollen uses to describe the various levels of the indicators.

[453] The question of perfect or absolute pitch is not dependent upon musical sophistication and thus not included in OMSI. This question could be added to OMSI if the researcher felt the presence or absence of perfect pitch could affect the results. The answer would not need to be treated as a quantifiable variable and included in Ollen's equation.

Table K.3.

Scoring template for Ollen Musical Sophistication Index[454]

Question number	Participant's answer	Regression coefficient	Selected values
1	______ X	.027	______
2	(No 0) X	-.026	______
3	______ X	-.076	______
4	______ X	.042	______
5	Rarely/never (0)	0	______
	1 hour/month (1)	-.060	______
	1 hour/week) (2)	-.098	______
	15 minutes /day (3)	-.301	______
	1 hour/day (4)	-1.211	______
	more than 2 hours/day (5)	-1.528	______
6	No	0	______
	(Yes)		
7	None (1)	-.423	______
	1 or 2 nonmajor courses (2)	.274	______
	3+ nonmajor courses (3)	-.616	______
	preparatory program (4)	.443	______
	1 yr of B. Mus (5)	.055	______
	2 yrs of B. Mus (6)	2.801	______
	3+ yrs of B. Mus (7)	.387	______
	B. Mus degree (8)	1.390	______
	Graduate level (9)	3.050	______
8	Never (0)	0	______
	bits and pieces (1)	.516	______
	none performed (2)	1.071	______
	for musical classes (3)	.875	______
	local audience (4)	.456	______
	regional or national audience (5)	-1.187	______
9	None (0)	0	______
	1 – 4 (1)	1.839	______
	5 – 8 (2)	1.394	______
	9 – 12 (3)	1.713	______
	more than 13 (4)	1.610	______
10	nonmusician (0)	0	______
	music-loving nonmusician(1)	-.553	______
	amateur (2)	.328	______
	serious amateur (3)	1.589	______
	semiprofessional (4)	1.460	______
	professional(5)	2.940	______
Constant			-3.513
	Add all selected values together	TOTAL:	

The data in Table K.4 is from two female participants of the same age, who began studying music at the same age, 8 years old. Both participants are singers and involved in performing. They diverge with respect to their level of music education, amount of time spent practicing, and the number of concerts attended in a year.[455] The

[454] Modified from Ollen, 241. The numbers in round brackets to the right of the choices are the rankings found in Table K.2 and were added by this author. Thus, the rankings in Table K.2 can be more easily linked to the indicators in Table K.3.

[455] Curiously, higher number of years of private lessons, more time spent practicing, and more time spent at live concerts result in lower values than does fewer years of lessons, less time spent practicing, and less time spent at live concerts. Higher self-ranking, more composing experience, and higher level of education give higher values than do lower self-ranking, less experience composing, and lower level of education.

results of OMSI are in agreement with the categories assigned in this present study. OMSI determined participant #3, defined as Expert by this study, has a 92% probability of being classified as musically sophisticated while participant #80, defined as Novice by this study, has a 38% probability of being classified as musically sophisticated. As with the parameters used in this study, Ollen's quantification of musical sophistication does not rely solely on musical skill or music education, but combines music education with experience of music to determine musical sophistication.

Table K.4.

Calculations of musical sophistication of two participants from present study

Ollen questions	Novice (participant #80)		Expert (participant #3)	
	Answer	OMSI	Answer	OMSI
1 (Age * 0.027)	57	1.539	57	1.539
2 (begin music lessons * -0.026)	8	-0.208	8	-0.208
3 (years of private lessons * -0.076)	8	-0.608	20	-1.52
4 (years of regular daily practice * 0.042)	20	0.84	45	1.89
5 (currently practice)	3	-0.301	4	-1.528
6 (university music courses)	no		yes	
7 (university music completed)	1	-0.423	7	0.387
8 (composing experience)	0	0	3	0.875
9 (number live concerts per year)	1	1.839	4	1.61
10 (title)	2	0.328	5	2.94
sum		3.006		5.985
logit (sum-3.513)		-0.507		2.472
$e^{logit} = e^{(1 + logit)}$		0.375897		0.922155
P (probability of musically sophistication)		0.38		0.92

APPENDIX L: THE ATTRACTIONAL CONTEXT AND EVENT GOVERNANCE RULES

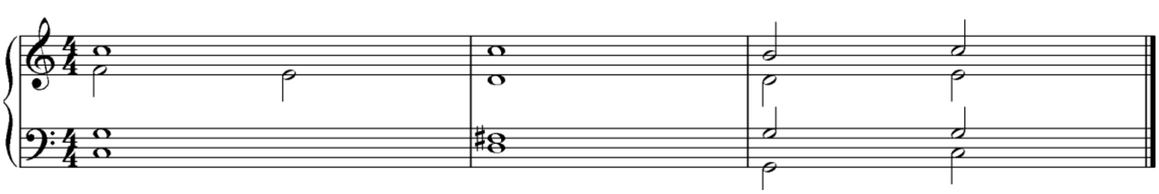
Lerdahl has proposed rules for determining the strength of attraction between pitches of a melody (Melodic Attraction Rule) and between the pitches of two chords (Harmonic Attraction Rule). If we liken melodic attraction to Lerdahl's pitch class space and harmonic attraction to chordal space, we are missing an element corresponding to regional space. In this model of attraction, regional space is called *Attractional Context* and its initial formulation states,

> In measuring the attraction on event e_1 exerted by e_2, calculate the attraction in the context to which e_2 refers.[456]

As an example, let us say e_1 is V^7 and e_2 is I. The attractional context rule instructs, to obtain the attraction of the pitches of V^7 to the pitches of I we must calculate in the context of I/**C**. Generally, however, compositions include chord tones, non-chord tones (chromatic and diatonic), and changes of local tonic. Since "pitches (whether harmonic or nonharmonic) exist in the context of chords and chords in the context of regions,"[457] Lerdahl formulates an *Event Governance Rule* to include the effect of local tonic or region. This new rule identifies the method for determining the region in which chords and pitches interact. According to the *Event Governance Rule,*

> Assume any pitch p_x, chord C_x, and region $\mathbf{R}_x$. Then,
> (1) p_x is governed by C_x, if p_x takes place in the span over which C_x extends, from the onset of C_x to the onset of C_{x+1}; and
> (2) C_x is immediately governed by $\mathbf{R}_x$ if C_x takes place in the span over which $\mathbf{R}_x$ extends, from the onset of $\mathbf{R}_x$ to the onset of $\mathbf{R}_{x+1}$; but
> (3) if there is a pivot chord C_p, the span of $\mathbf{R}_x$ overlaps with that of $\mathbf{R}_{x+1}$, such that $\mathbf{R}_x$ ends and $\mathbf{R}_{x+1}$ begins with C_p.[458]

Condition (1) indicates any pitch, harmonic or nonharmonic, is heard in the context of the chord sounding during the same time. The nonharmonic pitch F in Figure L.1a is governed by the chord C-E-G as is the harmonic pitch E. The chord C-E-G, and the nonharmonic pitch F, are governed by the region of **C**. The region of **C** governs until the V^7/**V** of Figure L.1b demonstrating condition (2). Condition (3) is demonstrated by I/**V** and V/**I** in Figure L.1c, where the region of **V** overlaps with the region of **I** at the G-B-D chord.



C: a) I/**I** b) V^7/**V** c) I/**V** and V/**I** I

Figure L.1 Examples of Event Governance.

Incorporating *Event Governance* with the initial form of the *Attractional Context Rule*, Lerdahl is now ready to formulate his final version of the *Attractional Context Rule* stating,

Assume pitches p_1 and p_2, chords C_1 and C_2, and regions $\mathbf{R}_1$ and $\mathbf{R}_2$, such that

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[456] Lerdahl (2001), 176.
[457] Lerdahl (2001), 177.
[458] Lerdahl (2001), 177.

(1) $p_1 \neq p_2$, but possibly $C_1 = C_2$ and $\mathbf{R}_1 = \mathbf{R}_2$

(2) p_1 is governed by C_1 and C_1 is governed by $\mathbf{R}_1$; p_2 is governed by C_2 and C_2 is governed by $\mathbf{R}_2$;

(3) if a realized attraction is computed and if

(a) p_1 and p_2 are in the same stream and

(b) $p_2/C_2/\mathbf{R}_2$ directly succeeds $p_1/C_1/\mathbf{R}_1$ at any given prolongational level, then $\alpha(p_1/C_1/\mathbf{R}_1 \rightarrow p_2/C_2/\mathbf{R}_2)$ such that

(4) if p_1 is nonharmonic, it is evaluated within the basic-space configuration of $C_1/\mathbf{R}_1$

(5) if p_1 is harmonic, it is evaluated within the basic-space configuration of I/$\mathbf{R}_2$.[459]

We can examine the conditions of the final version of the *Attractional Context Rule* by using the pitches, chords, and regions from the examples in Figure L.1. Let p_1 = F, C_1 = C-E-G, $\mathbf{R}_1 = \mathbf{C}$ and p_2 = E, C_2 = C-E-G, $\mathbf{R}_2 = \mathbf{C}$. This example meets condition (1) such that $p_1 \neq p_2$, but $C_1 = C_2$ and $\mathbf{R}_1 = \mathbf{R}_2$. Condition (3) is met as F and E are in the same stream and $p_2/C_2/\mathbf{R}_2$ directly succeeds $p_1/C_1/\mathbf{R}_1$. Because F is nonharmonic in this example, condition (4) is activated and p_1 = F is evaluated within the basic-space of C-E-G/**C**.

Beginning with the chord at Figure L.1.b, let p_1 = C, C_1 = D-F$^{\#}$-A-C, $\mathbf{R}_1 = \mathbf{G}$ and let p_2 = B, C_2 = G-B-D, $\mathbf{R}_2 = \mathbf{G}$ for the chord at Figure L.1.c_1. Next, consider the chord at Figure L.1.c_1 where we let p_1 = B, C_1 = G-B-D, $\mathbf{R}_1 = \mathbf{G}$ and follow it with a second chord, Figure L.1.c_2, where p_2 = C, C_2 = C-E-G, $\mathbf{R}_2 = \mathbf{C}$. In the first instance (L.**1b**→ L.$\mathbf{1c_1}$) or, V^7/**G**→I/**G**, C_2 = G-B-D is evaluated in the context of **G**. In the second instance, L.$\mathbf{1c_1}$→ L.$\mathbf{1c_2}$ or I/**G**→I/**C**, the same chord, now C_1 = G-B-D, is evaluated in the context of **R** = **C** as "a harmonic tone is evaluated in the context of the tonic configuration of the goal region."[460] This discussion should bring to mind the calculations for sequential and hierarchical tension in which one chord was found to have two different harmonic functions.

Lerdahl's model of melodic and harmonic attraction attempts to quantify listeners' experience of tonal music. He creates rules linking his three hierarchical musical spaces—pitch class, chord, and region. As with the time-span reduction, the prolongational reduction, and the prolongation tree, melodic and harmonic attraction in tonal music are dependent upon the relationships of pitches, chords, and regions, to a region or tonic. It is to the sometimes uncertain task of finding the tonic that Lerdahl now turns.

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[459] Lerdahl (2001), 178-179.
[460] Lerdahl (2001), 179.

APPENDIX M: FINDING THE TONIC

Since they were concerned primarily with tonal music, Rameau,[461] Weber,[462] Schenker,[463] and Kurth[464] all believe in the uniting and centralising force of the tonic. Each suggests several context-dependent methods for identifying the tonic. As we have come to expect, Lerdahl approaches this question from three perspectives—pitch class space, chordal space, and regional space. Much of his theorizing is reminiscent of Weber's theory of *Multiple Meaning*. Lerdahl also brings the subject of relative stability and his *Principle of the Shortest Path* to bear as he formulates the *Tonic-Finding Rule*. I will consider each space separately and conclude with the presentation of Lerdahl's *Tonic-Finding Rule*.

As a pitch class example, Lerdahl chooses pitch class 0 followed by pitch class 2 and suggests the listener is most likely to hear these pitches as ^1/**C** followed by ^2/**C**. Other possible hearings, such as ^7→^8 in **d**, ^5→^6 in **F**, and ^4→^5 in **G**, are less likely. Likelihood is related to stability. Stability is related to level of embedding in pitch class space, with the most stable pitch class being the least embedded pitch class. Figure M.1 shows three possible interpretations—in **C**, **F**, and **G**— of pitch class 0→pitch class 2. As ^4→^5 in **G** (M.1b) and ^5→^6 in **F** (M.1c), one or the other pitch class is embedded to the level of the fifth. Only as ^1→^2 in **C** (M.1a) is one of the pitch classes (pitch class 0) embedded to the most stable root level.[465] It is Lerdahl's contention the least embedded pitch class will be considered the tonic.

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[461] Rameau, in his *Treatise on Harmony* writes, "all properties of these chords [the perfect and seventh chords] depend completely on this harmonic center" and "everything is related solely to our harmonic center." Rameau (1722), 141-142.

[462] According to Weber, the "ear everywhere longs to perceive some tone as a principal and central tone … [because] the key in a piece of music is that particular system of tones on which, in one respect, the structure of a piece of music depends." Weber (1851), 254 - 255.

[463] For Schenker, tonality originates with the *Chord of Nature* or tonic triad and is symbolised by the *Ursatz* as it "offers the unfurling of a basic triad [and] it presents tonality on horizontal paths." Schenker, "The Urlinie: A Preliminary Remark," translated by R. Snarrenberg in *Der Tonwille Pamphlets in Witness of the Immutable Laws of Music, Offered to a New Generation of Youth*, 53.

[464] For Kurth, melodic and harmonic attractions exist in the context of tonality. Their relationship to tonality makes music expressive. "*First*, its musical effect depends on its relationship to the central tonic harmony, on its 'tonal function'." Rothfarb (1991), 119. [Italics in original]

[465] Recall, with depth, the level of embedding increases as stability decreases. The most stable and the least embedded level is the root level.

Level *a*	**0**											
Level *b*	**0**							7				
Level *c*	**0**				4			7				
Level *d*	**0**		**2**		4	5		7		9		11
Level *e*	**0**	1	**2**	3	4	5	6	7	8	9	10	11

a) pc0→pc2: ^1→^2 in **C**

a								7				
b			**2**					7				
c			**2**					7				11
d	**0**		**2**		4		6	7		9		11
e	0	1	**2**	3	4	5	6	7	8	9	10	11

b) pc0→pc2: ^4→^5 in **G**

Level *a*						5						
Level *b*	**0**					5						
Level *c*	**0**					5				9		
Level *d*	**0**		**2**		4	5		7		9		11
Level *e*	**0**	1	**2**	3	4	5	6	7	8	9	10	11

c) pc0→pc2: ^5→^6 in **F**

Figure M.1. Three possible tonic orientations for pc0→pc2. The pitch classes signify pitches of the tonic triads.[466]

Weber's *Principle of Inertia*[467] and Lerdahl's *Principle of the Shortest Path* also operate in chordal space. Lerdahl uses as his example the chord progression C→d. Once again, various interpretations are available—I→ii in **C**, V→vi in **F**, I/**C**→i/**d**. Weber's *Principle of Inertia* predicts I/**C**→ii/**C**. Lerdahl's value for *j* determined from the chordal circle-of-fifths is 2 for both Figure M.1a (I→V→ii)[468] and Figure M.1b (V→ii→vi). Although the *j* values are equal, indicating the lack of applicability of the *Principle of the Shortest Path*, only Figure 1.25a allows one chord to be considered the tonic. Choosing Figure M.1c, I/**C**→i/**d**, allows both chords to be considered tonics but does not conform to the *Principle of the Shortest Path*. According to Lerdahl, and Weber, the listener is likely to hear C→d as I→ii in **C** indicating listeners' preference for remaining in a key once established (Weber's *Principle of Inertia*) coupled with Lerdahl's *Principle of the Shortest Path*.

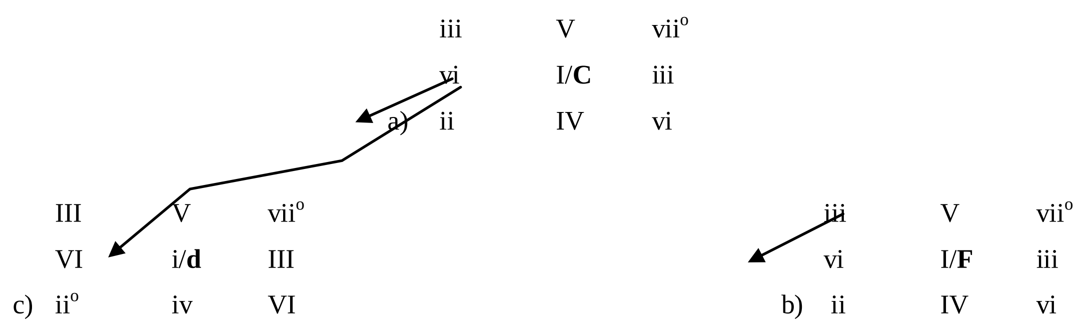

Figure M.2. Three possible tonic orientations for C→d.[469]

466 Lerdahl (2001), 195.
467 "The ear, once attuned to a particular key, does not change its state of attunement into that of another key without sufficient cause." Weber (1851), 333.
468 In Figure M.1a we move one step (around the chordal circle-of-fifths) from I to V and one more step from V to ii. In Figure M.1b we move one step from V to ii and one more step from ii to vi.
469 Lerdahl (2001), 197.

Lerdahl next addresses tonic finding in regional space, arising when both chords cannot be considered part of the same region. The chord progression C→E is such an example as C-E-G does not occur naturally in **E** nor does E-G#-B occur naturally in **C**. Figure M.3 charts three possible decisions listeners may make upon hearing this chord progression. They are as VI/**e**→I/**E**, I/**C**→V/**a**, or I/**C**→ I/**E**. The most unlikely choice is that which requires the listener to travel the furthest distance, I/**C**→ I/**E**. Both VI/**e**→I/**E** and I/**C**→V/**a** are equally plausible. If the first chord is determined to be I/**C**, the second chord, by virtue of the *Principle of the Shortest Path*, would be determined to be V/**a**. If, however, the second chord is determined to be I/**E**, the first chord, again by virtue of the *Principle of the Shortest Path*, would be determined to be VI/**e**.

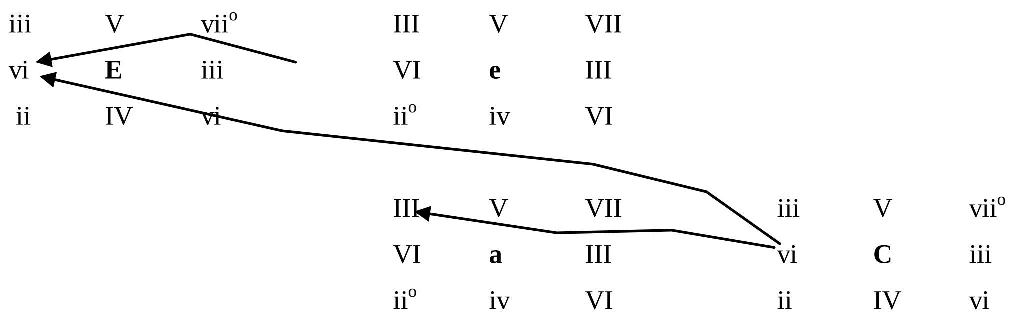

Figure M.3. Three possible tonic orientations for C→E.[470]

Lerdahl summarises the above arguments regarding tonic finding in pitch space, chordal space, and regional space as,

Tonic-Finding Rule: To establish tonic orientation in any time space or prolongational region at any level,

(1) if single pitches are under consideration, prefer the interpretation that places the pitches at the highest locations in the current basic-space configuration

(2) if chords are under consideration, prefer the interpretation that connects the chords by the shortest chordal/regional paths, both

(a) with respect to one another and

(b) with respect to the putative tonic at that level (without violating characteristic diatonic inflections in minor)

(3) if two events within a region are equally close to a tonic under different interpretations, or if the events do not fit in the same region, prefer the interpretation that forms the shortest path to the governing tonic at the next larger reductional level.[471]

The *Tonic-Finding Rule*, unlike the *Principle of the Shortest Path*, and the formulas for calculating distances in pitch class space, chordal space, regional space, or calculating attraction values, is a preference rule.[472] This means Lerdahl is setting out the preferred interpretation when determining the local or global tonic. He suggests other conditions affecting the choice of tonic include chord position, chord metrical position, and chord duration.

470 Lerdahl (2001), 199.
471 Lerdahl (2001), 199-200.
472 Recall, preference rules do not predict rightness or wrongness of a particular analysis. Instead, they suggest which, of the various alternatives, is the most likely.

These other factors must be considered when applying the *Tonic-Finding Rule* along with its reliance upon the stability and the *Principle of the Shortest Path*.

APPENDIX N: FUNCTION AS PROLONGATIONAL POSITION

Recall Lerdahl's depiction of chordal space (Figure 1.8) in which the chords of each of the three rows may be seen to correspond to the dominant (iii, V, vii^{o}), tonic (vi, I, iii), and subdominant (ii, IV, vi) functions.[473] Lerdahl does not confine himself to these three categories of function and suggests there are more functions acting in tonal music. His categories of function are not restricted necessarily to the type of chord as his emphasis is on how the chords function in the music rather than the category of the chords themselves. To this end, he formulates the *Function Rule* as,

> Given the repertory of functions T (tonic), D (dominant), S (subdominant), Dep (departure), Ret (return), N (neighboring), and P (passing), assign them by prolongational position from global to local levels, such that
>
> (1) T belongs to any pitch or chord that is a (local) tonic as established by the tonic-finding rule
>
> (2) D belongs to any chord
>
> (a) that is part of a labeled cadence, such that
>
> (i) for a full cadence, it left-branches into T, or
>
> (ii) for a half- or deceptive cadence, it left-branches to an underlying implied T, or
>
> (b) that is an applied (secondary) dominant
>
> (3) S belongs to any chord that left-branches to D
>
> (4) Dep belongs to any chord that is assigned a right-branching progression
>
> (5) Ret belongs to a noncadential chord that is assigned a left-branching progression to a chord that itself is a right prolongation
>
> (6) N belongs to any pitch or chord that is
>
> (a) directly subordinate within a strong prolongation or
>
> (b) a diatonic or chromatic step away from one of its directly superordinate events but not from the other ("incomplete N")
>
> (7) P belongs to any pitch or chord that is
>
> (a) directly subordinate within a weak prolongation or
>
> (b) a left branch off Dep
>
> (8) all functions transmit intact through strong or weak prolongations
>
> (9) parallel passages preferably receive parallel functions.[474]

Lerdahl, with the formulation of this *Function Rule*, addresses one of his criticisms of Schenker's approach to music analysis, which Lerdahl considers informal. Here, Lerdahl is cataloguing chord progressions typically found in Western tonal music, identifying their function, and providing the accompanying prolongational branching. Below are some examples found in *TPS*.[475]

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[473] The chords in the minor key are dominant (V, vii^{o}), tonic (VI, i), and subdominant (ii^{o}, iv, VI).
[474] Lerdahl (2001), 215-216.
[475] Lerdahl (2001), 217.

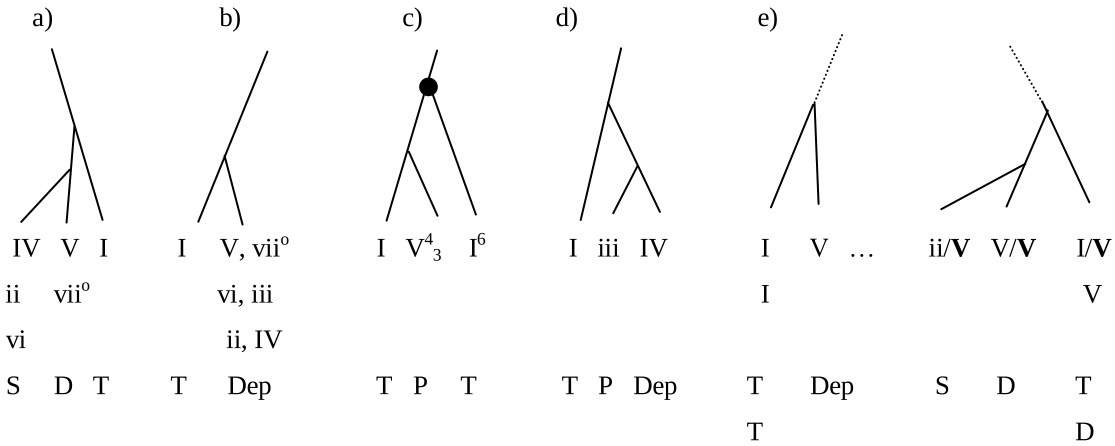

Figure N.1. Some examples of prolongational trees demonstrating Lerdahl's *Function Rule.*

Rules 1-3 are in effect in Figure N.1a, rule 4 in Figure N.1b, rule 7a in Figure N.1c, rule 7b in Figure N.1d. Figure N.1b combines with Figure N.1a to form Figure N.1e where the IV of Figure N.1a is replaced by ii/**V**, V by V/**V**, and I by I/**V**. Notice, I/**V** becomes V/**I** at a higher level. Figure N.1a indicates IV, ii, and vi may function as a left-branching subdominant to V or vii° (functioning as a dominant), which is a left-branch to I (functioning as a tonic).

The branching of Figure N.1a indicates the subdominant is subordinate to the dominant, which is subordinate to the tonic with each, in turn, representing relaxation with the arrival of successively more stable events. The right-branching V (vii°, vi, iii, ii, or IV) of Figure N.1b functions, not as a dominant, but as a departure, moving away from the stability of the tonic creating a sense of tension. The filled circle of Figure N.1c indicates a weak prolongation between I and I^6, both of which are functioning as tonics. $V^4{}_3$ is functioning neither as a dominant or a departure, but as a passing chord (^3→^4→^5) with its attendant feeling of tension. Figure N.1d shows a passing chord (iii) between a tonic (I) and a departure (IV). The branching in Figures N.1a, N.1c, and N.1d also shows several levels. Taking Figure N.1d as an example, the departure I→IV occurs at a higher level than does the iii passing between them.