Toward Pop Chord Space

Harmonic Hierarchy in Popular Music

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Tiivistelmä – Abstract

In this study, a set of 18 chord functions common in popular music is proposed and studied using the probing method. Two-chord probes, containing every permutation of the 18 chords (called the Pop Chord Set), are constructed and presented along with a key context to 21 subjects in a listening experiment. The participants are asked to rate the prevalence (or fitness) of the probe in the context of popular music. The results of the experiment (called the Pop Chord Space) are presented and compared to the Tonal Pitch Space model by Lerdahl. The main results suggest that *1)* the subjects have a tendency of favoring diatonic target chords over nondiatonic ones, and *2)* diatonic chords and, on the other hand, major chords, have the most paths open after them, and *3)* the models of harmonic hierarchy compared here have similar structural rules and tendencies, although *4)* there seems to be a perceived difference between harmonic hierarchies of different tonal musics (i.e. popular music and classical music). The concept of Pop Chord Space is later refined, and finally, limitations of this study are acknowledged, and recommendations for further research and musical practice proposed.

Asiasanat – Keywords

pop, popular, music, musical, harmony, harmonic, hierarchy, hierarchies, tonality, tonal, expectancy, expectations

Säilytyspaikka – Depository
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* In fact, the all-time heat record in Finland was broken the day I finished writing. The new record, now at +37,2°C (+99°F), was coincidentally measured in my hometown, Joensuu.

Honorary mentions go to **Microsoft** – for software that crash, and **Apple** – for making these crashes almost enjoyable.

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Conventions

Symbols

In order to avoid any compatibility issues, and to better facilitate certain cross-platform (computer software and operating system) file transfers, no special musical symbols are used in this document. Accidentals "♯" and "♭" are simply marked with "#" and "b", respectively. In addition, the symbol ">" is used to describe the direction of a (chord) progression, instead of an arrow ("→"). For example:

- F#7 = the F♯ (dominant) seventh chord
- *b*b = the note *b*♭
- C > a = the progression from C major chord to a minor chord

Absolute notation

Lower case Latin alphabets in italic type (*a* … *g*) are used for notes. Upper case Latin alphabets (A … G) are used for major triads, and lower case for minor triads (a … g). The number "7" denotes a (dominant) seventh chord. Musical keys are presented in boldface. For example:

- *c* = the note *c*
- C = the C major triad
- c = the c minor triad
- C7 = the C (dominant) seventh chord
- **C** = the key of **C** major
- **c** = the key of **c** minor

Relative notation

Arabic numerals (1 … 7) are used for notes. Upper case Roman numerals (I … VII) are used for major triads, lower case (i … vii) for minor triads. Diminished (minor) triads are marked with a "°", and augmented (major) triads with a "+". The number (along with a possible accidental preceeding it) indicates the position of the note or chord root in relation to a major scale sharing the same root (or tonic). For example:

- b6 = the note *a*♭ in the key of **C** major or **c** minor
- IV = the major triad F in the key of **C** major
- vi = the minor triad a in the key of **C** major
- vii° = the diminished triad b° in the key of **C** major
- bIII+ = the augmented triad E♭+ in the key of **c** minor

Chapter One: Introduction

In this chapter, we will first elaborate on the thesis title. There are certain concepts embedded in title itself, so we will look into them before engaging in the actual content. Next, the reader will be led from the practical background of this study, through the proposal of the research problem, and finally over to the hypotheses of results that are expected to surface along the way.

1.1 Definitions

Explanations of some key concepts, essential to the present study, are presented below.

1.1.1 Harmony

Harmony refers to the use of simultaneous *pitches* (*notes* or *tones*) of different pitch heights. Three or more simultaneous pitches constitute a *chord*. The pitches in a chord are usually of the same length, i.e. the pitches begin and cease to sound at the same time, although it is also possible to strongly imply harmony with a single voice by using *arpeggios* (notes of the chord played one after the other). In linear (or contrapunctal) writing, listeners often perceive interweaved melody lines producing harmonies, although the basic principle of contrapunctal writing is not chordal, per se. In *counterpoint*, the voices (two or more, creating a *polyphony*) are independent in contour and rhythm, but harmonically interdependent, as opposed to *monophony* (one voice only) or *homophony* (one melody voice accompanied by chords, as is the case in most forms of popular music).

The basic chord *qualities* are *major* (1, 3, 5, or *c*, *e*, *g*), *minor* (1, b3, 5, or *c*, *e*b, *g*), *augmented* (1, 3, #5, or *c*, *e*, *g#*), and *diminished* (1, b3, b5, or *c*, *e*b, *g*b). (Note: All examples from "*c*" onwards.)

1.1.2 Tonality

Tonality refers to a system of hierarchical pitch relationships, relating to the concept of musical *key*, centered around the *tonic* (or key center). The term tonality most often refers to *major-minor tonality* (also known as *functional tonality*) – the system of musical organization popularized during the *common practice*[1] period, and still in active use in Western music(s). In the Western tonal system, 12 *pitch classes* (*c … b,* constituting the *chromatic*[2] *scale*, see *Appendix A, Table 16),* recycled identically at each octave, are organized in subsets of seven *tones,* called a *diatonic*[3] *scale*

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[1] Common practice refers to a period (roughly spanning the years 1600–1900) in Western – mainly European – art music, including the Baroque, Classical, and Romantic periods, and broadly called classical music in layman's terms.
[2] A scale including all 12 pitch classes, and thus consisting of semitones (or minor second intervals) only.
[3] Belonging to a key (and/or a scale).

(see *Appendix A, Table 17*). For each scale, seven *diatonic chords*[4] are possible, each built on a different degree of the scale. Diatonic *chord degrees* are built by taking a scale degree, and superimposing other diatonic tones (usually separated by a diatonic third interval[5]) on top of it (see *Appendix A, Table 18*). The diatonic chords (along with their associated diatonic scales) constitute a musical *key*, indicated by a special symbol set in musical notation, and called a *key signature*[6].

Each tone and chord in the tonal system has a hierarchical function: a tone may be interpreted in reference to a key or chord – a chord, on the other hand, is usually interpreted in reference to a key. Tones are numbered with Arabic numerals in relation to a reference pitch – be it the tonic of a key or the root of a chord (for example, the tones of the diatonic C major scale: 1, 2, 3, 4, 5, 6, 7). Chords, instead, are numbered with Roman numerals in relation to the tonic (for example, the diatonic triads of the key of **C** major: I, ii, iii, IV, V, vi, vii°). The amount of perceived tension imparted to a piece of music by these tone and chord degrees is not absolute. Instead, it depends on a highly complex matrix of relative tonal-harmonic functions, studied in detail in scientific works presented in the next chapter, under "Previous studies on tonal hierarchies".

The basic chord functions are the *tonic*: I and vi ("C" and "a"), *subdominant*: ii and IV ("d" and "F"), and *dominant*: V ("G"). The function of the iii ("e") is somewhat ambiguous[7], and the vii° ("b°"), although usually designated as dominant, is extremely rare in dominant function[8]. (Note: All examples in **C** major.)

1.1.3 Popular music

Music genre classification is a task that becomes increasingly difficult year by year. The amount of music published, and the growing number of different genre taxonomies (in the Internet and the music industry), make definite genre classification of musical pieces a mission impossible. But of course, you can – and should – always try. Pachet and Cazaly (2000) did, and estimated that a database containing all recordings of tonal music would probably amount to four million titles.

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4 In this case, *triads* (a simultaneity of three tones: the root, third, and fifth) or *seventh chords* (a simultaneity of four tones: the root, third, fifth, and seventh) and their possible diatonic *extensions* (the ninth, eleventh, and/or thirteenth).

5 In practical terms: counting from the root (the first, or reference pitch of a scale), and taking every other diatonic tone to function as a chord member.

6 A series of sharp (#) or flat (b) symbols, placed at the beginning of the musical staff, and designating notes that are to be played one semitone higher or lower than the equivalent natural notes (*a* … *g*) – unless otherwise altered with an accidental.

7 Tonic or dominant or neither – depending on who you ask.

8 The vii° almost exclusively functions as a seventh chord ("-7b5", "m7-5", or "ø7") in secondary *subdominant* function (i.e. "B-7b5 > E7 > A-" or "II-7b5/VI > V7/VI > VI-" in C major). Note that these examples represent typical pop/jazz conventions in chord symbol (absolute) and harmonic analysis (relative) markings, and, as such, do not conform to conventions presented elsewhere in this study.

With the addition of non-Western musics, the figure would probably double or triple (Pachet & Cazaly, 2000). The authors went on to propose a new music genre taxonomy containing 378 genres. This number alone tells us that new genres and subgenres surface constantly. In addition, genres merge (and submerge) at a steady (or increasing) rate, making it easier to lose than keep track of the current, generally accepted genre classification, if there is one in the first place. With this in mind, it is proposed that for the purpose of this study, the term "popular music" shall refer loosely to music that appeals to popular tastes. In everyday language, this definition includes at least all forms of pop and rock music, as the term was presented to the subjects who participated in the experiment described later.

1.1.4 Expectancy[9]

Basically any event or parameter in music – be it dissonance, melodic contour, harmonic function, rhythmical pattern, metrical accent, or musical structure – can create expectations in the listener about what is going to happen next. Musical tension[10] is generally expected to end with the release of tension. In practice, this implication (or expectation) can be either realized or inhibited, creating musical meaning and affect (see Meyer, 1956 and Narmour, 1990 for details). Expectations are discussed in more detail in the next chapter, under "Previous studies on musical expectations".

1.1.5 Priming

According to Tillmann (2008), the *priming paradigm* is an "implicit investigation method that studies the influence of perceivers' expectations on the afficiency of perception (i.e. accuracy and processing speed)". This method makes it possible to study nonmusicians' musical perception without requiring explicit knowledge about the rules of the musical system. In practice, a *prime* context (usually a tone, scale, chord, or chord progression) is presented to the subjects, followed by a *target* event (a tone or a chord). The relation between the two is then systematically manipulated. It is assumed that the (prime) context generates expectations for future (target) events in the listeners, with strongly related effects being more expected. These expectations, in turn, influence event processing (i.e. processing being facilitated for expected events). (Tillmann, 2008)

In addition to being implicit, the priming paradigm is also indirect, meaning that the subjects are not asked to make explicit judgments on the relation between the prime and the target, but instead, they

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[9] A note on terminology: According to Eerola (2003), the terms "expectancy" and "expectation" are used rather carelessly among scholars, although "expectancy" should refer to the *general state* of being expectant, and "expectation" to a more *specific action* of anticipating something.

[10] As a matter of fact, musical tension and musical expectancies are quite related according to Bigand et al. (1996).

are asked to focus on a different perceptual feature of the target (i.e. its consonance/dissonance or out-of-tuneness). Priming is discussed in greater detail in the next chapter, under "Expectancy in music psychology".

1.1.6 Probing

"Probing" refers to the *probe-tone (or probe-chord) techinque*. It is explained in the next chapter, under "Expectancy in music psychology".

1.2 Background

Songwriting – the craft of creating new pieces of popular music – has interested and inspired generations of musicians; artists, composers, and lyricists alike. Songwriting as a hobby – or even as a means of earning income – has traditionally been very approachable in that it is, at best, relatively low cost in nature: all you need is some spare time, a creative mind, possibly a musical instrument, and a medium (a pen and a paper, or a recorder) for making records of the progress. What is it then that recurringly makes songwriting the priviledge of a few – usually the ones with at least basic skills in musical harmony? What about aspiring songwriters (i.e. singers or drummers) with basic skills in playing a harmony instrument, such as the guitar or the piano, but with too little to no skills in harmony? I have faced these questions countless times while teaching songwriting to future music professionals.

There are a few basic tools in the professional songwriter's toolkit – one of them being some sort of a schematic representation of the most common chord progressions found in songs belonging to a particular genre of music. This representation can exist physically (i.e. as a chart), or it can be a mental scheme internalized while being exposed to music (i.e. by listening, playing, and/or writing). Some years ago I started to collect one such representation with the help of my students attending a songwriting course called "Hittitehdas" (Finnish for "Hit Factory") at the Jyväskylä College. One of the objectives of the course was to gather as many common chord progressions found in popular music (especially in hit songs) as possible, and bring them to the classroom, so that they could be organized on large sheets of paper. It turned out that, indeed, many of the chord progressions were shared by several songs, and, in addition, most of the sequences shared similar structural and harmonic properties. First, upon closer inspection, practically all chord progressions found seemed to be multiples of two measures in length, with four measures being the most frequent implementation by far. Second, the progressions included some chords that did not belong to the diatonic chord set of the prevailing key (or "the key of the moment").[11] At the same time, they were not perceived as resulting from modulations either, so they were deemed modal interchange chords[12] by default (see Nettles & Graf, 1997 for a review). Third, the chords were mostly triads[13], excluding secondary dominants[14] that were usually seventh chords. Fourth, some of the progressions clearly had more "hit potential" than others, evident by the fact that for some chord sequences, it was relatively easy to find hit songs that these particular chords (in a particular order) were used on, as aptly demonstrated by Raskopoulos et al. (2009) in their hilarious YouTube video[15] of 36 (well, in fact 34 – as one of them is a duplicate, and one self-written) hit songs conforming to the same age-old chord progression of four chords (I > V > vi > IV, or in the key of **C**: C > G > a > F). To sum up, hit harmonies were found to be generated from the following chord categories: *1)* diatonic triads, *2)* secondary dominants, and *3)* modal interchange chords. Chords *not* in wide use in popular music were substitute dominants and various (secondary and substitute) subdominants.

A couple of years and a few courses later, a satisfactory pool of familiar chord progressions had accumulated. Completely new and unique sequences were not surfacing anymore, so it was decided it was time to organize them so that they could be of use when writing songs. The plan was to present the progressions in an approachable format for the novice songwriter – to answer the question "I'm at chord X now – where's my Y?" in form of an easy-to-navigate "road map" of tonal-harmonic terrain of popular music.

The chord progressions were eventually organized in pairs, based on their tonal function (Tonic [T], Subdominant [S], and Dominant [D]). The paired organization was chosen because, according to Nettles and Graf (1997), the perceptual weighting of the harmonic rhythm follows a repeated-pair

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[11] For example, in any major key: the "bIII" in *Sgt. Pepper's lonely hearts club band* (The Beatles), *Born To Be Wild* (Steppenwolf), *Let Me Entertain You* (Robbie Williams), *Fields Of Joy* (Lenny Kravitz), *Knock On Wood* (Eddie Floyd), and *Purple Haze* (Jimi Hendrix); the "v" in *Uptight* (Stevie Wonder), *Save Your Love For Me* (Nancy Wilson), *Millennium/You Only Live Twice* (Robbie Williams/Nancy Sinatra), and *I Never Loved You Anyway* (The Corrs); the "bVII" in *With A Little Help From My Friends* (The Beatles), *Miracle* (The Queen), *Orinoco Flow* (Enya), *Star* (Earth Wind & Fire), *Celebration* (Kool & The Gang), and *Ghostbusters* (Ray Parker, Jr.).

[12] Chords borrowed from a mode sharing the same root – the most common example being chords borrowed to a major key from the parallel minor key.

[13] Several common "slash chords" (a triad on top of a bass note) were found – most of them simple chord inversions, and thus not assumed to affect chord function.

[14] Temporary dominants to the diatonic chord degrees. For example, in the key of **C**, "E7" is regarded as a secondary dominant to "a" ("V7 of vi" or "V7/vi"), since the default resolution of all secondary dominants is a perfect fourth up (e.g. *e* to *a*) into a diatonic chord.

[15] The Axis of Awesome (self-titled as "Australia's most tolerated musical comedy trio"): *4 Chords*, which has been viewed for almost three million times as of July, 2010. As a curiosity, the very video has clearly inspired others to explore the same subject, producing similar "copycat" contributions (e.g. a video called *4 Chords, 65 Song*s).

scheme (Strong > Weak | Strong > Weak) in a typical four-measure chord progression in quadruple meter – arguably the most common meter in popular music. This paired weighting schema is supposed to apply to all levels of harmonic rhythm, including the measure and beat levels (with their doublings, quadruplings etc.). Harmonic function, on the other hand, was chosen as the common denominator at the highest organizational level, because it happens to *be* the highest organizational level of within-key harmony. In addition, reharmonization by chord function[16] is one of the most common reharmonization techniques used in songwriting, composing, and arranging. This technique is facilitated if the map is arranged by chord function. In the end, the "road map of hit song harmony" ended up being structured as follows:

Table 1.
The simplified road map of hit song harmony.

1. Tonic > X*	**2. Subdominant > X**	**3. X > Secondary dominant***
a) T > T • I > X • vi > X	a) S > T • ii > X • IV > X	a) T > V • I > V7/X
b) T > S • I > X • vi > X	b) S > S • ii > X • IV > X	b) S > V • IV > V7/X
c) T > D • I > X • vi > X	c) S > D • ii > X • IV > X	c) D > V • V > V7/X

Legend: T = Tonic, S = Subdominant, D = Dominant, V = Secondary dominant

** The "iii" chord was relatively rare in tonic (or any other) function. For simplicity's sake, it was excluded from this presentation, although it was included in the original charts.*

*** Only the primary Tonic, Subdominant, and Dominant functions (I, IV, and V) were included in these pairings, because the other T/S/D functions (vi, ii, vii°) were rarely paired with secondary dominants – the "vii°" never.*

Note that "Dominant > X" progressions are not included in the map, because dominants rarely occupy metrically strong beats or measures, based on the principles of harmonic rhythm (Nettles & Graf, 1997) (see *Table 2* below).

Table 2.
Harmonic rhythm in relation to chord function in quadruple meter (adapted from Nettles & Graf, 1997).

Beat or measure	*1*	*2*	*3*	*4*
Strength	S	W	S	W
Chord function	T or S	D or V	T or S	D or V

Legend: S = Strong, W = Weak, T = Tonic, S = Subdominant, D = Dominant, V = Secondary dominant

[16] In essence, a chord possessing a certain harmonic function can usually be replaced (or reharmonized) with another chord sharing the same function (e.g. "C > F" in the key of **C** major can often be replaced by "a > F", "C > d", or "a > d", because all these pairings share the same functional structure "T > S").

Table 3 (below) represents a small fraction of the complete road map of hit song harmony. The full table extends downward in order to include all four-measure variations of chord progressions beginning with "I > V" (i.e. I > V > vi > iii, as in *Cryin'* by Aerosmith, and I > V > IV > V, as in *Luka* by Suzanne Vega). The next instance on the map (vi > V) is represented by a similar table with its own real life examples of hit songs, and so on.

Table 3.
The detailed road map of hit song harmony. Only the first instance of condition "1. c)" (T > D … I > X … I > V) from table 1 (above) is shown here for reference.

First chord pair	**I > V**			
Chord function (relative)	I	V	vi	IV
Chord symbol (absolute)	C	G	a	F
Measure	*1*	*2*	*3*	*4*
Hit songs*	*Don't Stop Believing* (Journey), *You're Beautiful* (James Blunt), *Right Here Waiting* (Richard Marx), *No One* (Alicia Keys), *Happy Ending* (Mika), *Lovesong* (Amiel), *Where Is The Love* (The Black Eyed Peas), *Amazing* (Alex Lloyd), *Wherever You Will Go* (The Calling), *Glycerine* (Bush), *Twenty Good Reasons* (Thirsty Merc), *High* (Lighthouse Family), *Soul To Squeeze* (Red Hot Chili Peppers), *Sway* (Bic Runga), *Cigarettes Will Kill You* (Ben Lee), *She Will Be Loved* (Maroon 5), *With Or Without You* (U2), *Fall At Your Feet* (Crowded House), *Not Pretty Enough* (Kasey Chambers), *Let It Be* (The Beatles), *Under The Bridge* (Red Hot Chili Peppers), *Man In The Mirror* (Michael Jackson), *Can You Feel The Love Tonight* (Elton John), *Down Under* (Men At Work), *Waltzing Matilda* (Banjo Patterson), *Take On Me* (A-ha), *Save Tonight* (Eagle-Eye Cherry), *Africa* (Toto), *Self Esteem* (The Offspring), *Dammit* (Blink 182), *Apologize* (One Republic), *Canvas Bags* (Tim Minchin), *Torn* (Natalie Imbruglia), *Scar* (Missy Higgins)			

** In this case, the 34 hit songs proposed by Raskopolous et al. (2009).*

Now, let us imagine a situation where a, say, singer or drummer with basically no skills in harmony wants to write a pop song. He or she knows the basic chords on a harmony instrument, and wants to start with the tonic (the "I" or "C" in **C** major). With no skills in harmony, the aspiring songwriter could end up being lost after one chord only, but this is not the case with the one with access to the "complete map of hit song harmony". With the help of the map described above, the novice songwriter can explore common harmonic options found in real songs, and either conform to the common practice, or alternatively oppose the choices with built-in hit potential, in order to create something never heard before – something personal and unique. "Well, this I > V > vi > IV is not taking me where I wanted to go originally, so let's try I > V > vi > iii instead...", I hear the aspiring songwriter say with a piano in front of her – or a guitar on his lap.

1.3 Research problem

As presented above, with the advent of the "road map of hit song harmony", it was finally possible for the novice songwriter to relate to what had already been done, and inversely, what had *not* been done yet. These binary black-and-white answers, extracted from the actual songwriting practice of popular music, were good enough for most of the students, but not for some – they wanted to see the shades of gray. They still got lost with all the options available, and wanted to know how *likely* or *common* it was for certain chords to resolve into others in a given harmonic context. Little did they know that they were going to have to answer this question by themselves by taking part in this research. Enter the "road map of hit song harmony, v2 – now enhanced with probabilities"!

The question proposed above was the sole motivator behind this study. Apparently, there was a practical need for a songwriting tool that would indicate *a)* the chords that are common in popular music, *b)* the chords that a certain chord is likely to resolve into in a popular music context, and *c)* the prevalence (or built-in hierachy) of these resolutions. The first question was halfway answered: the "pop chord set" was already proposed – now its existence only had to be proven. In addition, the amount of available chord degrees had to be narrowed down to a manageable focus, in order not to rule out any relevant research methods, such as listening experiments, by exploring all chords in all tonalities ever known to mankind. In the end, major tonality, with its related chord degrees, was chosen as the focus of this study for two reasons: *1)* modal interchange chords are far more common in major than in minor, and *2)* minor tonality with its multiple modes is inherently more complex (and versatile) than major, in that the diatonic chord degrees in a minor key can be seen to include chord degrees from all its parallel modes.[17] Finally, it was decided that the prevalence of chord X resolving into chord Y was going to be studied in one metric position only (Strong to Weak)[18], because *a)* the inclusion of the other position (Weak to Strong) would have doubled the amount of progressions to examine, and *b)* the results found by studying the "X > Y" chord pair in measures 1–2 was speculated to apply to measures 3–4, too, based on the principles of harmonic rhythm. This level of detail was seen as more than adequate for the purpose of this study.

The research problem described above was derived from everyday challenges in musical practice, namely songwriting. In addition to this practical perspective, there were several other questions of subsidiary practical interest, but of primary scientific interest. One such question stood head and shoulders above others when the research problem was considered: based on the initial survey on hit song harmony, it seemed that modal interchange chords were more frequent in popular music than in classical music, so it was deemed interesting to see how high they would rate in the hierarchy. In other words, would the harmonic hierachy of all tonal musics – including Western common practice and popular – end up being declared universal? On a related note, it was also

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[17] This is known as the concept of "combined minor" or "compound minor", where the chord degrees of the most common minor modes (the natural, harmonic, ascending melodic or "jazz", and "dorian" minor) are combined together. In this system, all possible permutations of the minor scales' upper tetrachord (note degrees 5 … 8) are included: 5, b6, b7, 8 in natural; 5, b6, 7, 8 in harmonic; 5, 6, 7, 8 in ascending melodic or "jazz"; and 5, 6, b7, 8 in "dorian" minor.

[18] "Strong" to "Weak" metric stress in measures 1 to 2 of a four-measure chord progression (or the same concept doubled in measures 1 & 2 to 3 & 4).

regarded as interesting to try and find out how well the harmonic hierarchy of popular music would correlate with similar models of classical harmony – or whether it would correlate at all.

All the questions raised above are formulated into scientific hypotheses, and presented below.

1.4 Hypotheses

First, it is expected that the chords constituting the "road map of hit song harmony" (diatonic triads, secondary dominants, and modal interchange chords) are perceived as belonging to the default chord set in popular music.

Second, it is expected that the internal hierarchy of this default chord set correlates positively with one (or some) of the models of harmonic hierarchy proposed in prior scientific studies presented in the next chapter.

Third, it is expected that the to be presented model of harmonic hierarchy in popular music differs in some aspect(s) from earlier, classical models. The "counterclockwise" major chords[19] on the circle of fifths are expected to reside higher in the harmonic hierarchy of popular music.

[19] Modal exchange chords that include non-diatonic tones (e.g. Bb, Eb, and Ab in **C** major).

Chapter Two: Literature

In this chapter, a brief overview of some benchmark studies on tonal harmony is presented. First, we will look at some music-theoretical and music-psychological studies with focus on *harmonic priming*, followed by a closer look on certain studies on *tonal hierarchies*. Both harmonic *expectations* and harmonic *hierarchies* are covered in this literature review, because these fields of study often overlap, and as we will soon find out.

As a side note, the working title of this study was "Toward Pop Chord Space: Harmonic *Expectations* in Popular Music", until I found out – after having acquainted myself with the studies presented below – that musical expectations are often investigated by utilizing the priming paradigm, which, in the strict sense, means that the main focus is on the *afficiency* of perception, and not on the actual *results* of the perception process. Now, the main objective of the present study is to find out *which* chord ("Y") the listeners expect to hear after another chord ("X") in a given context (key), and *how well* it fits its surroundings. So in a way this study still deals with listeners' expectations, but the *influence* of their expectations on perception speed or accuracy is not measured. Instead, the *target* of their expectations, revealing an underlying harmonic hierarchy, is.

2.1 Previous studies on musical expectations

Musical contexts generate expectations about upcoming musical events in listeners (Bigand et al., 2003). Musical expectations have been thoroughly studied or hinted at by both music theorists (Schenker, 1935/1979; Meyer, 1956; Ratner, 1966; Piston, 1978; Lerdahl & Jackendoff, 1983; Narmour, 1990) and cognitive music psychologists (Bharucha & Stoeckig, 1986, 1987; Tekman & Bharucha, 1992; Tillmann & Bigand, 2001; Tillmann et al., 2003; Bigand et al., 2003).

2.1.1 Expectancy in music theory

Schenker's (1935/1979) basic harmony (*Ursatz*) utilized expectation to form the structures of melodic motion (*Urlinie*). Meyer (1956), on the other hand, suggested that the generation of expectations forms the basis of the perception of musical emotion and meaning. In his opinion, musical passages become meaningful in reference to others – through fulfilled or violated expectations: "… one musical event … makes us expect another musical event", and "… emotion or affect is aroused when a tendency to respond is arrested or inhibited" (Meyer, 1956). Among other things, Meyer's application of general Gestalt laws of perception to musical events (melodic patterns, namely) was later adopted by Narmour (1990). In addition, Meyer also noted that our expectations may be quite specific or rather unfocused, and, on the other hand, quite strong or rather weak. The former aspect of expectation has been characterized as "expectancy specifity", and the latter as "expectancy strength" by Schmuckler (1989).

Contemporary theory of harmony of Western tonal music would not be a coherent whole without the contributions of Walter Piston and Leonard G. Ratner. Ratner (1966) brought the existence of "resting positions" (toward which musical events move) to the table, whereas Piston (1978) provided us with the "Table of Usual Root Progressions", where the most common chord progressions in Western tonal-harmonic music are outlined. Lerdahl and Jackendoff (1983) presented a concept of prolongational reduction of musical events, in which events creating tension are connected with points of relaxation – essentially conforming to a classic dualist model (i.e. antecedent/consequent) of expectancy formation. A similar bipolar structure can be found in Narmour's (1990) implication-realization model, which describes tone-to-tone expectations of melodic continuations – paying homage to Meyer's (to whom Narmour's book is dedicated, by the way) work a few decades earlier. Following Narmour, Parncutt (1999) expanded on the model by applying the concept of implication-realization to tonality induction. He reported finding at least four simultaneous implication-realization effects in a passage of tonal music leading to an authentic cadence.

2.1.2 Expectancy in music psychology

Bigand et al. (2003) suggested that both sensory and cognitive processes potentially govern harmonic priming, and that both are present when listening to music. According to the authors, a context may prime the processing of chords that either *a)* share the same harmonic spectra, referred to as *sensory priming*, or *b)* are related to it according to the rules of a given musical idiom, referred to as *cognitive priming* (Bigand et al., 2003). In the following paragraphs, sensory and congnitive approaches are discussed separately, although in some studies (i.e. Tillmann et al., 2008), the findings are discussed with references to both.

Sensory priming

Schmuckler (1989) suggested that “a chord sharing component tones, or overtones, with a preceding chord will be more highly anticipated than a continuation containing no overlapping frequencies with its predecessor”. This notion sums up the basic idea of sensory priming: the strength of harmonic relationship between chords may thus be predicted without explicit knowledge of Western rules of harmony. This view is well illustrated in the sensory model of Parncutt (1989), which rates the harmonic relatedness of chords based on the pitch commonality of successive chords. The pitch commonality values of Parncutt (1989) were later weighted according to chord recency by Bigand and Pineau (1997). This psychoacoustic model – along with several others (i.e. Huron & Parncutt, 1993) – added sensory memory decay to the equation, to better reflect the accumulation of sensory traces of musical events in sensory memory. This can be seen as an important addition, especially when longer musical passages are considered.

In addition to shared harmonic spectra between chords, sensory priming is also related to the frequency of occurrence of the target in the preceding context: the more often a target chord occurs in a context, the higher its pitch commonality value (Bigand et al., 2003). As Bigand et al. (2003) admitted, cognitive and repetition priming may have had an effect on the results of the Bigand and Pineau (1997) study, in which tonic targets occurred more often in the prime context than subdominant targets, suggesting that it is sometimes difficult to separate sensory priming from cognitive priming.

Cognitive priming

It is generally accepted that the Western tonal-harmonic system is internalized through mere exposure to Western music (Cuddy & Badertscher, 1987; Koelsch et al., 2000; Koelsch et al., 2003; Krumhansl, 1990; Krumhansl, Bharucha, & Kessler, 1982; Regnault, Bigand, & Besson, 2001; Tillmann, 2008; Tillmann, Bharucha, & Bigand, 2001). In cognitive priming, the context can be seen to activate the listener's knowledge of Western harmonic hierarchy, which in turn results in faster processing of target chords "closer" to the present key context.

Bharucha and Stoeckig (1986) presented a priming procedure in which subjects were presented with two successive chords (a prime followed by a target) that were either closely or distantly related harmonically. The subjects were then asked to make a true/false decision about the target chord quality. It was found that major targets were identified faster (and with fewer errors) when they were related, demonstrating that the processing of a target chord is facilitated when it occurs after a harmonically related prime. In subsequent studies, Bharucha and Stoeckig (1987) arrived at similar results, even though the stimuli did not have overlapping harmonics or share component tones. Furthermore, Tekman and Bharucha (1992) found out that the priming effect did not diminish with time (with up to 2500 msec of stimulus onset asynchrony) or a noise mask inserted between the prime and the target. These results suggest that these effects were produced at a cognitive rather than sensory level, although the method can be argued having had its limitations: first, it did not take melodic features into account, and, in addition, the sounds used were very different from those of actual musical instruments – especially because the complexity of their harmonic spectra was reduced.

Later, similar priming effects have been found while studying longer musical contexts (Schmuckler & Boltz, 1994; Bigand & Pineau, 1997; Bigand, Madurell, Tillmann, & Pineau, 1999; Tillmann & Bigand, 2001). In addition, Tillmann et al. (2003) further elaborated on the subject of harmonic priming by adding a baseline condition (sequences without a tonal center) to the equation. The (rather obvious) results suggest that an activated tonal center generates strong expectations for the tonic. Although the contexts may have grown longer since the Bharucha and Stoeckig (1986, 1987) experiments, some of the aforementioned studies have been criticized (as in Bigand & Pineau, 1997) of not taking account of the effects of global and local harmonic context on expectancy formation, although the importance of higher levels of musical structure have been emphasized earlier (as in Lerdahl and Jackendoff, 1983).

Global and local context effects

Bigand and Pineau (1997) found support for the effects of global harmonic contexts on expectancy formation by carrying out three experiments, where eight-chord sequences were presented to subjects, while varying the expectations for the last chord by manipulating the harmonic content preceding it. The global context effect was later studied by Tillmann and Bigand (2001), who investigated whether harmonic priming in chord sequences was going to show effects of temporal order similar to semantic priming in sentences. The authors studied normal and scrambled chord sequences in three experiments with the following predictions in mind: first, harmonic expectations developing during a musically coherent sequence are likely to differ from expectations that develop during a less coherent sequence, and second, if a key-finding algorithm (such as the one presented in Krumhansl, 1990) manages to indentify the key of musical excerpts without considering the temporal order of the musical events, there should be no decrease in priming in scrambled sequences (Tillmann & Bigand, 2001). Interestingly, the subjects exhibited a sensitivity to the temporal order of events when judging musical coherence but not when performing a priming task.

Formal support for these results was found when the experiments were simulated with Bharucha's (1987) connectionist MUSACT model, where tones (the twelve tones of the chromatic scale) are linked to (major and minor) chords, which are, in turn, linked to (major and minor) keys, forming a three-layer network of interconnected units. Tonal hierarchies are then represented by the strength of the connections between the units. Whenever a chord is presented to the model, activation reverberates via connected links between layers, and units of harmonically related chords are more strongly activated than units of unrelated chords. The network structure itself is atemporal, but because action accumulated in the network is weighted according to recency, it is able to capture some dynamic characteristics of harmonic expectations as they develop over time (Tillmann &

Bigand, 2001). In other words, the MUSACT model represents both *activation* and *accumulation* of activation patterns when applied to the study of tonal knowledge and harmonic priming. The model has become quite popular since its inception, demonstrated by the sheer number of published studies (e.g. Bigand et al., 1999; Tillmann et al., 2000; Tillmann et al., 2003) utilizing it.

Recently, Tillman and Lebrun-Guillaud (2006) investigated the influence and interaction of expectations in pitch ("What note/chord?") and time dimensions ("When?") on chord processing and completion judgments. It appears that pitch and time dimensions interact for completion judgments only, suggesting that the interaction of pitch and time is favored in global level (i.e. completion) judgments, while local level (i.e. priming) judgments rely on independent influences of the two dimensions instead.

Music and psycholinguistics

Researchers have been drawing parallels between different domains of science for quite some time. Several studies on music perception have been closely linked to studies in psycholinguistics, for example the Tillmann and Bigand (2001) study presented earlier. More recently, Patel and his colleagues have focused on studies supporting Patel's (2003) shared syntactic integration resource hypothesis (SSIRH), which suggests that "music and language draw on a common pool of limited processing resources for integrating incoming elements (such as words and chords) into syntactic structures" (Slevc, Rosenberg, & Patel, 2008).

Music and the human brain

Musical expectations have been investigated with *event-related brain potentials* (ERP) in several studies, many of them relating to language studies (i.e. Regnault at al., 2001; Tillmann et al., 2003; Loui & Wessel, 2007). Patel (2003) noted that the "language areas" of the brain are activated by musical *syntactic processing* (i.e. reacting to incongruous or "wrong" notes at the end of a melody), which elicits a *late positive [brain] component* (the P600 event-related potential – a neural correlate of language processing), starting soon after the onset of a word, and peaking at about 600 ms. Patel et al. (1998) found that the P600 is statistically indistinguishable for both language and music processing, suggesting that language and music can indeed be studied in parallel. In addition to the P600, Patel et al. (1998) found both *early and late right-anterior negative components* (RATN, or right antero-temporal negativity) elicited by the processing of music. These two components, distributed over the left and right hemispheres of the human brain, respectively, are thought to reflect both general processes of knowledge-based structural integration (P600) and the application of music-specific syntactic rules during music perception (RATN) (Patel et al., 1998). Besides syntactic processing, *semantic processing* – reflected in the negative component N400 – also plays a central role in language understanding, but since its association with the processing of music has not been studied extensively (Koelsch, et al., 2000), we will leave the topic for the time being.

2.1.3 Other features governing expectancy formation

In addition to the tonal-harmonic hierarchy (discussed in the previous chapters), several other features, such as melody (melodic interval size and melodic contour) and rhythm, govern expectancy formation in Western music. Because they are beyond the scope of the current study, the interested reader is advised to get acquainted with the excellent article *Rhythm and Pitch in Music Cognition* by Carol L. Krumhansl (2000).

2.2 Previous studies on tonal hierarchies

In the previous chapter, studies focusing on harmonic expectations were presented from the viewpoints of music theory and music psychology, respectively. The harmonic priming paradigm was further discussed in relation to sensory and cognitive processes. The same (sensory vs. cognitive approach) structure is applied to this chapter, too, but for the purpose of this study, it is important that they be assessed side by side, so that it will be easier to choose the approach(es) against which the results of the current study will be put up later on. For a more comprehensive view on the subject, please see *Perception of musical tension in short chord sequences: The influence of harmonic function, sensory dissonance, horizontal motion, and musical training* by Bigand et al. (1996), in which the effect of horizontal organization on perceived musical tension is studied, in addition to the vertically inclined (as in emphasizing the effect of harmony) approaches presented below.

Let us begin by stating that pitches in tonal contexts are indeed hierachically differentiated (Krumhansl, 2000). Similar differentiation can be seen to apply to chords and keys (especially in regard to modulations). According to Lerdahl (1998), a tonal hierarchy is a nontemporal mental schema, used by listeners in assigning event hierarchies to pitch sequences. An event hierarchy, on the other hand, is a part of the structure that listeners decode from temporal musical sequences (Lerdahl, 1988). This nontemporal element sets studies on tonal hierarchies apart from studies on, for example, harmonic priming, although some models of tonal hierarchies have later been "refined" by superimposing simulations of the effect of sensory memory decay on top of the original models: the pitch commonality values of Parncutt (1989) modified by Bigand and Pineau (1997), and the harmonic hierarchy of Krumhansl (1990) modified by Huron and Parncutt (1993).

2.2.1 Sensory models

Sensory models (or psychoacoustical theories) of musical tension predict the strength of harmonic relationships between successive chords without considering the listener's implicit knowledge of (Western) tonality (Bigand et al., 1996).

Roughness values

In as early as 1863, Helmholtz (1885) already noted that the dissonance of a chord (presented in isolation) depends on its perceived roughness. Plomp and Levelt (1965) took the concept a step further by showing that the perceived roughness of a pair of pure tones depends on the critical band distance of the components (or tones). Some years later, Hutchinson and Knopoff (1978) applied the Plomp and Levelt (1965) findings to actual music, namely chords. In their model, the notes constituting a chord were at a similar level (having equal amplitudes), and had ten harmonics each (tuned to equal temperament). In addition, the amplitudes of the harmonics were proportional to the reciprocal of their harmonic number ($1/n$), so that the first harmonic was the loudest (1/1), the second half as loud (1/2), and so on. The Hutchinson-Knopoff model was later fine-tuned by Bigand et al. (1996), by approximating the original Plomp & Levelt (1965) "standard curve" – sampled by Hutchinson and Knopoff (1978) – with a mathematical function. The original model can be considered rather primitive by today's standards, because it does not take into account the mutual masking of the chord components (or tones), or recognize that the contributions to overall roughness may not add linearly (Bigand et al., 1996).

Pitch commonality

(Note: The pitch commonality model was already briefly referred to in the previous chapter under "Sensory priming".)

In traditional Western music theory, successive chords are seen as closely related if they have (one or more) common tones, or if they (or their roots) reside close to each other on the cycle of fifths. According to Bigand at al. (1996), the latter condition cannot be unequivocally measured, because the roots of the chords are generally somewhat ambiguous, although (in my humble opinion) this does not apply to the majority of popular music. Be what it may, Parncutt (1989) saw the need to devise a model that would not have to rely on the listeners' knowledge of music theory, or tonality in general, in predicting the strength of harmonic relationships between successive chords.

Parncutt's (1989) model predicts the harmonic distance of chords by calculating the degree to which they have perceived pitches in common. These perceived pitches may differ from the actual notated pitches, because of the existence of *implied pitches* (or *virtual pitches*) that may not even be physically present, but are "hinted at" (or implied) by the sounding tone or chord. These virtual pitches can result from, for example, conceivable common tones between successive chords, or the harmonic components of tones present (or implied).[20] In action, the pitch commonality model first outputs a profile of pitches (actual and virtual) and their predicted saliences, followed by a pitch commonality value, calculated by comparing successive pairs of pitch profiles, so in essence, the output value is nothing but a correlation coefficent of the two pitch profiles. This model can be criticized of being somewhat mechanical and therefore rather remote from the actual musical practice. For example, if we consider the chords c minor and C major in the context key of **C** major, the odds are that the minor chord will be perceived by listeners as being quite distant from the key context. In contrast, the pitch commonality model regards the two chords as being extremely close to each other. In addition, the model is not octave generalized (i.e. two chords an octave apart receive dissimilar ratings), and as such, it may differ from the musical experience of the average listener with equal-tempered ears, so to speak.

2.2.2 Cognitive models

The following two models can be regarded as being cognitive in nature, because they both assume that the listeners have accumulated implicit knowledge of the Western tonal system.

Harmonic hierarchy

A musical key (i.e. **C** major) consists of a set of seven diatonic notes (i.e. *c*, *d*, *e*, *f*, *g*, *a*, and *b*), from which the chord degrees belonging to the key in question are created by taking each note (now called the root) one at a time and then adding other diatonic notes, usually every second note of the scale (or notes separated by a diatonic third interval), on top of it, so that each chord contains at least three notes (three to four for basic diatonic functions). The resulting seven chords (i.e. C, d, e, F, G, a, b°) are not created equal: some of them will have a more important function in tonality induction than others, resulting in a *within-key hierarchy*. On the other hand, the number of notes shared between two musical keys results in a parameter called *between-key distance*. Listeners, be they experts or novices, have internalized these key concepts of harmonic hierarchy by mere exposure to Western music (Krumhansl, 1990).

Krumhansl investigated tonal hierarchies and key distances in several experiments (Krumhansl & Shepard, 1979; Krumhansl & Kessler, 1982; Krumhansl, 1990). In the ones relevant to this study,

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[20] According to Terhardt (1974), the subsidiary pitches arising from chords may increase the salience of certain tones, and thus have an effect on the perception of the chord root. For this reason, the virtual pitches are often considered as pitches corresponding to a *missing fundamental*.

she utilized the so-called probe-tone (or probe-chord) technique. (For simplicity's sake, I shall refer to this method as "probing" – as opposed to "priming", for example.) Probing involves the presentation of a key-defining *context* (a scale, a chord, or a chord sequence) which is followed by a *probe* (a tone, or a chord). The listener is then asked to rate how well the probe fits with the musical context. In the Krumhansl and Shepard (1979) study, the contexts were ascending (*c*4 … *b*4) or descending (*c*6 … *d*5) incomplete C major scales, and the probe tones were an octave's worth of pitches of the chromatic scale beginning on the middle *c* (*c*4 … *c*5). Listeners were asked to rate how well the probe tone completed the scalar context.

A couple of years later, Krumhansl and Kessler (1982) elaborated on the research design of the original study by using complete scales, tonic triads, and harmonic cadences as contexts – now transposed to various keys. They also used octave-neutral "Shepard tones" or "circular tones"[21] to focus the subjects' attention on pitch class hierarchy only – in essence minimizing the side effects of (unintentional) voice leading and chord inversions. The results of these experiments were highly congruent on many fronts: strong influence of neither context type nor different keys was found, and, in addition, the results were consistent for both "one listener across many trials" and "many listeners across one trial" conditions. This study resulted in the now classic[22] Krumhansl and Kessler (major and minor) key profiles (as seen in Krumhansl & Kessler, 1982; Krumhansl, 1990: Table 2.1, and Fig. 2.3), which have been corroborated (and criticized) in studies too numerous to mention here. In short, the first tone of the scale (tonic) is the most stable one, followed by the fifth scale degree (dominant) and the third scale degree (mediant) – then the remaining scale degrees, and finally the nondiatonic tones (Krumhansl, 2000).

In 1990, it was Krumhansl's turn to replicate the earlier (1979 and 1982) studies, but this time with chords instead of tones. In the two experiments conducted, Krumhansl (1990) attempted to measure the structural stability and harmonic hierarchy of chords in a tonal context. Again, the trials started with a key-defining context, followed by a probe (a single triad). Listeners were asked to rate how well the chords fit with the context. Circular tones were again used for both the context and the probe. To sum up the results, the tonic triad (I), dominant (V), and sometimes the subdominant (IV) were considered most important for establishing the key, while the second (ii) and sixth (vi) degree minor triads were considered somewhat weaker, and the chords built on the third (iii) and seventh

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[21] sounds resulting from superposition of (ten) sinusoidal components separated by octaves – the amplitudes at the extremes being close to treshold, and well above treshold for those in the center (see Shepard, 1964 for further details)
[22] according to Google Scholar (alone), the article had been cited 399 times in scientific publications by July 20th, 2010

(vii°) played the weakest roles in defining the key (Krumhansl, 2000).[23] Listeners' ratings were again highly consistent across different contexts and modes (major and minor, with major mode ratings being more consistent of the two) (Krumhansl, 1990). Several analyses – and results – followed: first, major triads received the highest fitness ratings, followed by minor and diminished triads, respectively, then, diatonic triads were found to receive higher ratings than non-diatonic triads, and finally, triads whose component pitch classes were ranked high in the tonal hierarchy, received the highest fitness ratings.

Krumhansl used the key profiles (or probe ratings) of both tonal (Krumhansl & Kessler, 1982) and harmonic (Krumhansl, 1990) hierarchies to derive a measure of *interkey distance*. The correlations of similarity values between pairs of keys were subjected to non-metric multidimensional scaling (MDS, also NMDS) in order to produce a spatial representation of interkey distance. A four-dimensional model was found to represent the data best, with two dimensions for the circle of fifths distance (e.g. **C** to **F** and **G**), and two for the parallel (shared tonic, e.g. **C** – **c**) and relative (shared key signature, e.g. **C** – **a**) major-minor relationships. A two-dimensional rectangular representation of this toroidal model can be seen in *Figure 1* below (on the left). Keys spatially close to each other on the map are perceived as being closely related in a perceptual sense (Patel, 2003). It should be noted here that both tonal and harmonic hierarchies were found to yield similar measures of distances between keys (Krumhansl, 2000), hence the single map. This map was found to correspond with earlier music-theoretic models, such as the "Chart of the [Key] Regions" by Schoenberg (1983 [1954/1969]) (*Figure 1*, on the right), which, in turn, was originally inspired by (or copied from) Gottfried Weber (Lerdahl, 1988; Dudeque, 2006) (*Figure 2*).

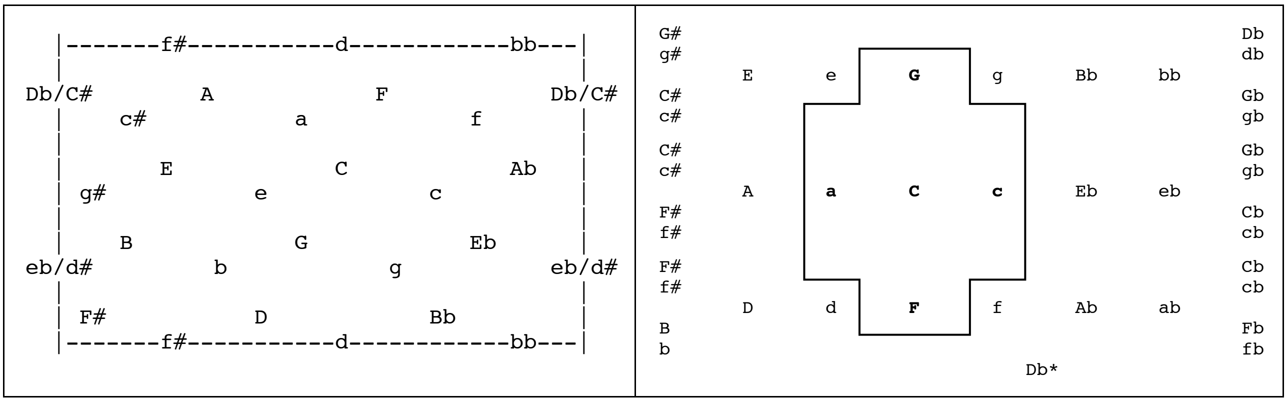

Figure 1. Left: A spatial representation (or a map) of interkey distance (adapted from Krumhansl & Kessler, 1982). Note how the left and right (and the top and bottom) edges are connected, reflecting the circular nature of key relations. Right: Chart of the [Key] Regions in **C** major (adapted from Schoenberg, 1983 [1954/1969]). Note the two-dimensional presentation and reversed circle of fifths orientation compared to the Krumhansl and Kessler (1982) model.

[23] Detailed ratings can be found in Krumhansl, 1990: Table 7.3, and Table 7.7.

** As a curious side note, this "outlier" (in Figure 1, on the right) refers to the Neapolitan (sixth) chord – the bII degree of a given key (usually found in its first inversion, and favored by the likes of Chopin, for example).*

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              A

          d   D   b

      Bb  g   G   e   E

  eb  Eb  c   C   a   A   f#

      Ab  f   F   d   D

          bb  Bb  g

              Eb
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Figure 2. A schematic diagram of major-minor key relations (adapted from Weber, 1846 [1817–1821]).

Krumhansl (1990) noted that the distance between major keys is well represented by the circle of fifths, but the three scalar forms of minor keys (natural, melodic, and harmonic minor) complicate matters considerably. I have to disagree with her, and agree with Lerdahl (1988), who noted that the differences between the minor scales can be viewed as scale-degree-specific voice-leading tendencies, which are context-dependent deviations within a natural-minor framework. As a result, natural minor can be regarded as the "default minor". After all (and in regard to the current study), the majority of popular music in minor keys is almost exclusively composed in natural minor.

In sum, the discovered psychological measures correlate strongly with the distribution of tones in tonal-harmonic music (Krumhansl, 1990), suggesting that the tonal hierarchies are learned through experience (Krumhansl, 2000). These tone distributions have been suspected to have an effect on the listeners' ability to determine musical keys. Krumhansl and Schmuckler (in Krumhansl, 1990) devised an algorithm that matches the tone distribution in musical samples to the tonal hierarchies measured in the experiments (Krumhansl & Kessler, 1982; Krumhansl, 1990) described above. This *model of key finding* has later been adopted and elaborated on by several scholars: for successful modeling of key-finding with neural network models involving self-organizing maps (SOMs), consult the works of Leman (1995) and Toiviainen and Krumhansl (2003). In addition to these key-finding models, a few other musical applications for self-organizing maps have since emerged (e.g. Janata, 2007).

Tonal Pitch Space

Various results suggest strong dependencies between perceived pitch structure at the following three levels: tones (or notes), chords, and keys (Krumhansl, 2000). To recap (see *Harmonic hierarchy*): first, the fitness of the chord tones in the tonal hierarchy dictates the harmonic hierarchy of chords within a key; second, the interkey (or between-key) distances can be calculated by using both tonal and harmonic hierarchy profiles as source material, and third, these distances produce a toroidal map of key relations, organized by two factors: the circle of fifths distance, and the relative and parallel major-minor key relations (Krumhansl, 2000). Lerdahl's (1988) *Tonal Pitch Space* model combines these three types of distances into a single integer value. With the model, it is possible to mathematically compute the psychological distance between two chords (any chord in a key and another chord in the same or a different key). The basic idea of the model is to represent the tonal hierarchies in three embedded spaces – the first two representing within-key hierarchies, and the third one the between-key distances (Bigand et al., 1996).

The first space is called *pitch-class proximity*. It contains five levels: *1)* chromatic, *2)* diatonic, *3)* triadic, *4)* fifth, and *5)* root. In a given context (in this case a tonic C major triad in the key of **C** major), a tonic tone is represented at all five levels, a dominant tone at the fifth (fifth above the root) and all lower levels, and the mediant at the triadic and all lower levels. A nonchordal (diatonic) tone is represented at the diatonic and chromatic levels, and a nondiatonic tone at the chromatic level only (Bigand et al., 1996) (see *Table 4* for a visual representation).

Table 4.
Pitch-class proximity of a tonic triad (C major). If a tone is represented on any (or all) of the five levels, it is marked with an "X". The tones are represented on the vertical (Y) axis, and the levels reside on the horizontal (X) axis.

	1) Chromatic	**2) Diatonic**	**3) Triadic**	**4) Fifth**	**5) Root**
root/tonic (*c*)	X	X	X	X	X
fifth/dominant (*g*)	X	X	X	X	
third/mediant (*e*)	X	X	X		
diatonic (nonchordal)	X	X			
nondiatonic	X				

Note. Lerdahl's (1988) model was later expanded to discriminate between triads and seventh chords by Bigand et al. (1996). In the revised model, the seventh of a chord is represented at the triadic level. Therefore, adding a seventh to a triad produces one change in pitch-class proximity if the seventh belongs to the key (a "diatonic 2" value becomes a "triadic 3"), and two changes if it is a nondiatonic tone (a "nondiatonic 1" value becomes a "triadic 3") (Bigand et al., 1996).

The second space is called *chord proximity within a key* (or region). Lerdahl (1988) devised a formula computing the distances separating the diatonic chords by taking account of *a)* the number of steps separating the roots of the chords on the circle of diatonic (or relative) fifths (in **C** major: *c – g – d – a – e – b – f*), and *b)* the number of changes in pitch-class proximity created by the second chord. For example, the note *g* on a C major triad is represented on the fifth level (Level 4), but the same note on a following G major triad will be represented on the root level (Level 5), essentially creating a level change of "1" in pitch-class proximity.

The third, and final, space is called *distances between keys* (or regions). Lerdahl's (1988) formula computes *a)* the distances between tonic chords of different regions, and *b)* distances between chords of one region to chords of another region, taking account of *a)* the number of steps separating the regions on the chromatic (or absolute) circle of fifths (*c – g – d – a – e – b – f#*/*g*b – *c#*/*d*b – *a*b – *e*b – *b*b – *f*), and *b)* the number of changes in chord *and* pitch-class proximity produced by the change of key. For example, let us consider the distance between the keys of **C** major and **G** major. The keys in question are one ("1") step apart on the circle of fifths, with five ("5") changes in chord-class proximity, and one ("1") change in pitch-class proximity (the note *f#* is diatonic in **G** major and nondiatonic in **C** major), resulting in a distance of "7".

All in all, Lerdahl hypothesizes that greater spatial (not temporal, that is) distances between musical events, such as chords, results in greater degrees of perceived musical tension. The upside of this approach is that the model formalizes and quantifies the different interpretations that a musical event, such as a chord, can receive. The inevitable downside, on the other hand, is that the distance values are, in the end, calculated according to a formula, and not perceived by human ears and processed by the human brain.

Nevertheless, Bigand et al. offer us one solution in specifying which interpretation of a musical event, such as a chord function, will be preferred by listeners in a given case. With long chord sequences, the global structure of the piece directs the listener towards a simple interpretation of the chord function, but in short sequences, the interpretation is less clear. Listeners are in general assumed to follow a simple economical principle – *the principle of the shortest path*. In other words, listeners are assumed to perceive chords so that their distances from the tonic are minimized. (Bigand et al., 1996)

For a clear presentation of chord distances in tonal pitch space according to the principle of the shortest path, see *Table 1* in Bigand et al. (1996, p. 129).

Summary

Western harmony has been studied systematically for centuries. It has also received a great deal of attention compared to melody, for example. In the words of the late German composer, conductor and music theorist Paul Hindemith, "It is an astounding fact that instruction in composition has never developed a theory of melody" (as quoted in Lindblom & Sundberg, 1969). This may be partly true, but when we look at the progress made in exploring musical expectations and tonal hierarchies during the past couple of decades, one can only wonder where does this range of different perspectives and cross-domain creativity come from.

There are a couple of critical gaps midst this wealth of knowledge, though. First and foremost, the majority of the studies focus exclusively on music from the common practice period, so there must be a huge pool of other, equally as great music(s) waiting for future scholars to dive into. The existence of this substantial gap was recently brought up by Tillmann (2008). The number of studies concerning popular music, for example, is small but hopefully growing.[24] In addition, there can never be too many commercial and practical applications for scientific studies, in my opinion. After all, it is these applications that often help ordinary people make and/or enjoy music. There are two such fields of study that I have watched with great interest recently: the automatic prediction of hit songs and automated music recommendation systems – both with robust scientific backgrounds and a commercial focus. Another field of study, full of practical applications of harmonic knowledge, is automatic accompaniment. The research in question usually aims for commercial use in (home) keyboards and automatic accompaniment software, and the results of these studies are often protected by patents (see *Appendix B* for a list).[25] Finally, other gaps (or inadequately explored territories) in the literature, pointed out by researchers, are cross-cultural studies, studies of non-Western and ethnic music cultures, brain studies, and studies on meter and rhythm.

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[24] Recent studies relating to popular music: Chuan and Chew (2007) devised a system for automatic generation of style-specific accompaniment, using songs by Radiohead to evaluate the model. In addition, Nichols et al. (2009) presented a system for the exploration of chord sequences, using a database of popular music to extract harmonic features from.
[25] The patents are included here, because in my opinion, interesting parallels can be drawn between them and some of the studies (especially the ones focusing on key-finding) presented in this chapter. (Just watch out for bad English.)

Chapter Three: Methodology

To recapitulate, the principle research questions addressed by this study were the following:

1. What chords are common in popular music?
2. What are the chords that a certain chord is likely to resolve into in a popular music context?
3. What is the prevalence of these resolutions?

In addition, a subsidiary question was brought up:

> Does the model of harmonic hierarchy presented in this study correlate with similar models of classical harmony? In other words, do all tonal musics share the same universal rules of harmonic hierarchy?

The principle questions (1–3) and the former part of the subsidiary question will be discussed thoroughly and systematically during the course of this study, while the latter part of the subsidiary question, being so vast, will receive just enough attention to hopefully serve as a hypothesis for a future study.

3.1 Research design

First, a "Pop Chord Set", containing common chords found in popular music, is proposed. The Pop Chord Set functions as the core of the research material, so its structure and contents need to be thought out very carefully. For this reason, an entire subchapter (see below) is dedicated to the definition and presentation of the Pop Chord Set. Next, the interrelatedness of the chords belonging to the Pop Chord Set is studied with the chosen research method(s). The collected data is then organized and analyzed using statistical tools and methods. Eventually, the results of the study are presented, and findings discussed. Based on the findings, some preliminary components constituting a system that may very well be called "Pop Chord Space" is proposed. Finally, the limitations of the study are acknowledged, and recommendations for further study proposed. In addition, suggestions for practical applications of the Pop Chord Space follow.

3.1.1 Pop Chord Set

In the "road map of hit song harmony", presented in *Chapter 1.2*, commong chord progressions were extracted from a random sample of popular music, containing hundreds of hit songs. It was found out that the majority of the chords included in the progressions could be generalized into the following three functional categories:

1. diatonic triads,
2. secondary dominants, and
3. modal interchange chords[26].

For the purpose of this study, we will from now on refer to the group of chords belonging to the aforementioned categories as the "Pop Chord Set" (presented in *Table 5* below).

Table 5.
The Pop Chord Set (chords presented in ***C*** *major).*

Modal interchange	**c** i	~~**d°**~~ ~~ii°~~	**Eb** bIII	**f** iv	**g** v	**Ab** bVI	**Bb** bVII	*chord* *function*
Diatonic triads	**C** I	**d** ii	**e** iii	**F** IV	**G** V	**a** vi	~~**b°**~~ ~~vii°~~	*chord* *function*
Secondary dominants	**G7** V7(/I)	**A7** V7/ii	**B7** V7/iii	**C7** V7/IV	**D7** V7/V	**E7** V7/vi	(N/A) (N/A)	*chord* *function*

Legend: N/A = Not available

Chords common to jazz harmony, for example, that were *not* found widespread in pop songs included the following:

1. substitute dominants
2. secondary subdominants, and
3. substitute subdominants.

In addition, the following chord categories, although occasionally found in pop songs, were ruled out, because they were not considered as being able to explicitly change the basic tonal *function* of chords presented in *Table 5* above:

1. suspended chords (sus2, sus4) and chords with additional tones (add9, add11),
2. "slash chords" (triads over bass notes, most often simple triad inversions), and
3. seventh chords (other than V7/X) and chords with extensions (9, 11, and/or 13)

Finally, the few diminished chords found in pop songs were either working as secondary dominants (vii°7/X, sometimes regarded as "upper structures" of secondary dominant seventh chords, e.g.

[26] In this case, modal interchange refers to chords "borrowed" to a major key (**C** major) from the parallel natural minor key (**C** natural minor, or the C aeolian mode in modal terms). Some of these chords (most notably the "v" or "g" and "bVII" or "Bb") can in some cases be regarded as modal interchange chords from the parallel mixolydian mode (C mixolydian), but since this distinction is not essential to this study, we will not let it complicate matters further.

G#°7 ≈ E7) or appeared in a minor key context, rendering them beyond the scope of this study.[27] The rare (in pop) blues chords (such as the "IV7") were also excluded, because they come from a different genre than the one under study.

Diatonic triads

All diatonic triads (chord degrees of the prevailing key) were included in the Pop Chord Set for obvious reasons, except for the "vii°" that was not encountered – at least in strict diatonic vii° function – in any of the chord progressions extracted. This view is supported in several respected theory textbooks (e.g. Piston, 1978) and scientific studies (e.g. Krumhansl et al., 1982).

Secondary dominants

All secondary dominant chords of the aforementioned diatonic triads were naturally included in the Pop Chord Set. Note that the V7(/I) chord ("G7" in **C** major), which is commonly regarded as the *primary* dominant (V7) of a major key, is put in the secondary dominant category in order to separate it from the diatonic V ("G" in **C** major) triad. Also, note that the (theoretical) "vii°" chord does not have a secondary dominant associated with it, because one of the core features of secondary dominants is their ability to "tonicisize" diatonic chord degrees. In other words, a genuine secondary dominant chord must be able to imply the possibility of a standard dominant-to-tonic resolution between it and the diatonic target. Since a diminished chord, such as the "vii°", cannot function as a (temporary) tonic, the "V7/vii°" does not exist – at least in music (although on the paper it might).

Modal interchange

All modal interchange chords borrowed from the parallel natural minor key were also included in the Pop Chord Set, except for the "ii°" chord, which was excluded for similar reasons as the diatonic "vii°" chord in major was. After all, the "ii°" chord (e.g. "d°") of the parallel minor key (e.g. **c** minor) is actually a "vii°" in the relative major key (e.g. **Eb** major) of the parallel minor. Note that the "i" chord, although never discovered from actual songs, was not removed from the Pop Chord Set, because its exclusion was neither supported nor opposed in previous studies. It was also thought that, in the end, it might be good to have a practically nonexistent "control chord" within the set, in case its inclusion would end up contributing valuable information to the study. For a reference, Johansson (1999) reported that in the 194 Beatles songs in major keys (of a total of 210

[27] For an excellent, practical presentation on diminished seventh chords in jazz, see Nettles & Graf (1997), p. 110 onwards. In short, the authors present three diatonic functions (*ascending* [a semitone up]), *descending* [a semitone down], and *auxiliary* [no root motion]) for diminished seventh chords, of which only the last one has a traditional dominant function.

songs), the "bVII" chord was more frequent that the diatonic "iii" chord, for example. Other modal interchange chords found in the music of the Beatles were the "iv", "bIII", and "v". In my opinion, these findings alone are enough to support the inclusion of modal interchange chords in any study of tonal harmony in popular music.

To summarize, the Pop Chord Set was proposed to include a total of 18 chords – six diatonic triads, six secondary dominants, and six modal interchange chords.

3.2 Research method

Being focused on music making in practice, and teaching of practical musical skills, I basically had no other choice than to trust the human ear as my main source of information. In other words, I was not going to get any wiser about how people really perceive music (harmony in particular) by dwelling on the physical or acoustical properties of chords and chord progressions. Instead, I chose to carry out a listening experiment, hoping for results that would be of use in teaching harmony and songwriting (and in the actual songwriting process) – eventually put into practice by practically anybody interested in the outcome of the study.

Although listening experiments – especially if poorly planned beforehand – can sometimes be accused of being rather inaccurate and highly subjective, they still carry important information about the way certain musical events make us feel and react. After all, what is enjoyment and appreciation of music like if not "inaccurate" and "subjective"? Besides, by careful design, an experiment can still output accurate quantitative data, and be firmly rooted in musical practice at the same time. In addition, experiments in general can be seen to hold great potential for establishing cause-and-effect relationships. Like Krumhansl (1990) stated, the experimental method is a good place to start: it is simple and illustrative in nature, and in addition, there are clear intuitions and theoretical predictions to compare results with.

Since I was going to investigate, among other things, the dynamics of chord pair *resolutions* in popular music, I had to come up with a research method that would quantify perceived relations between two chords, and at the same time, take care that all the pairings would be evaluated in the given tonal context. The research questions proposed earlier were already steering this study toward a quantitative research on harmonic hierarchies. Krumhansl (1990) had studied the degree of relatedness between two tonal elements[28] earlier, using a variant of the original probe-tone (or

[28] First with tones in Chapter 5 – then with chords in Chapter 8 (see Krumhansl, 1990).

probe-chord) method[29] – this time with a two-part (or dual) probe. The trials shared a similar structure: a key-defining unit followed by two tones (or chords) presented in succession. The listeners were then asked to rate how well the second tone (or chord) followed the first in the key context provided. In essence, she was asking the subjects to rate how (subjectively) *good* the continuations were. I was interested in that, too, but I also wanted to touch on the topic of how (objectively) *common* it was for the first chord to resolve into the second one in a popular music context. This is why I decided to ask the subjects to rate the *prevalence* of the chord resolutions. Of course, the subjects still make subjective decisions in the latter example, but at least they aim for objectivity. Bigand et al. (1996) also faced similar problematics when their results, measuring *musical tension* created by one chord, were compared with the data from the Krumhansl studies, measuring *goodness of fit*. The authors suggested that these methods can be considered as two strongly related ways to measure the same thing, so in essence, musical tension and goodness of fit can be seen as two sides of the same coin (Bigand et al., 1996). As you can see, the difference in perspective with all these methods is slight, but as they say, the devil is in the details.

It was decided that the basic concept of the stimuli would be derived from the Krumhansl trials presented above, but slight modifications were to be made. First, I wanted to use complex tones (i.e. sounds of real musical instruments) in my experiment, as opposed to Shepard tones, for example. By doing this, I wanted to impart a feeling of realism to the experiment, and to constantly remind the participants of the genre under study. Realistic sounds have been used in experiments like this before, and the results have been found to correlate significantly with studies utilizing Shepard tones (see Bigand et al., 1996). Second, as the stimuli were decided to be as realistic as possible, both the context and the probe had to be musically consistent. Since the study concerned harmonic phenomena, the probe obviously had to consist of chords, and so did the context, for the sake of consistency. The sole reason for the inclusion of the context element in these experiments is to remind the listener about the prevailing musical key in reference to which the probes are rated. It was decided that a sense of key[30] would first be established by a perfect cadence[31] in **C** major. Third, because the probe element in this method is divided in two parts, I wanted to name them so that they could be referred to easily. At first, I considered "X" and "Y", but decided to discard the idea because these symbols cannot be used as verbs. At the risk of confusing matters even worse, I

[29] See Krumhansl and Shepard (1979) and Krumhansl and Kessler (1982).
[30] According to Krumhansl (2000), the tonic (I) and dominant (V) – sometimes along with the subdominant (IV) – are considered most important when establishing the key.
[31] "I > IV > V > I" or "T > S > D > T" or "C > F > G > C" in the key of **C**.

finally ended up naming the former "X" and "Y" as "prime" and "target". Knowing well that this study is, strictly speaking, not about priming, I still could not imagine a better, more descriptive pair of words for the purpose of this study. After all, the main focus of this study is in chord resolutions, and it always takes two to tango in resolutions: the musical event needs to be prepared (or *primed*) first with chord "X" and then resolved into chord "Y" (the *target*).

3.2.1 Source of information

With the research method decided upon, I had to come up with a method of accessing the population under study. The population in question being us human beings in general, it seemed obvious that the target population was too large to be managed, so a population sample had to be selected. The selection was eventually done by convenience (subjects readily available) and purposive sampling (subjects with certain characteristics).

I decided to focus on experts in music, regularly exposed to Western tonal music – especially popular music. As a full-time staff member at a music college, it was self-evident for me to turn to my students for voluntary help in the name of science. Luckily for this study, the pop/jazz students at Jyväskylä College happened to be (arguably) the most "pop-oriented" ones within the Finnish Music Campus (which Jyväskylä College is a part of). In order to get reliable and statistically significant results, I decided to aim for 20 to 30 volunteers.

3.3 Data collection

In order to collect experimental data for the study at hand, a listening experiment was conducted. The experiment, consisting of four separate listening sessions, took place in Jyväskylä, Finland in May, 2009. Each subject had to attend two of the four sessions with 162 stimuli (audio excerpts) each, in order to evaluate all 324 pairs of Pop Chord Set chords. The schedule of the experiment was designed to be as flexible as possible so that *a)* most of the participants could complete the assignment without excessive rescheduling of personal calendar events, and *b)* the order of the stimuli could be changed between (spontaneously created) groups of subjects.

3.3.1 Sample access and ethical issues

All participants were orally asked for permission to use data provided by them for scientific and educational purposes. At once, full confidentiality and anonymity was granted to them.

3.3.2 Subjects

A questionnaire, investigating the participants' background information, was devised as part of the experiment. The subjects' age and gender was already known, so only the following queries were printed on the actual questionnaire sheet: *1)* formal music education (in years), *2)* main instrument (melody, harmony, rhythm, or none), *3)* popular music listening habits, and *4)* the subject's primary musical style. The first two questions were included in order to be able to investigate whether the amount of music studies and/or their choice of main instrument would correlate with the participants' answers. The last two questions were included only to make sure that they all listened to popular music, and that none of them would be associated to a single genre (e.g. jazz or classical) outside the scope of this study.

A total of 21 music students (7 female and 14 male) with a mean age of approximately 22 years from Jyväskylä College volunteered to participate in the experiment. All of them had enrolled in college in order to obtain a upper secondary level vocational qualification in music. On average, they had had 6 to 10 years of formal musical education: 7 of them for 1–5 years, 5 of them for 6–10 years, 8 of them for 11–16 years, and one of them for as long as 16–20 years. Eight of the participants played a melody instrument (or sang), ten of them played a harmony instrument (the guitar or the piano), and three of them played a rhythm instrument (the drums). The participants reported listening to popular music at least on a weekly basis (a mean of 4.33 with a value of "4" denoting weekly, and "5" daily listening) – half of them listening to pop every single day. The participants' preferred musical style was almost unanimously "all-around" (20 out of 21 responses, with one diehard rock'n'roller in the bunch), although 15 other, more specific styles were provided as an option in the questionnaire. For a detailed view on the forms used, please refer to *Tables 19–20 in Appendix C*.

3.3.3 Stimuli

The stimuli used in the experiment were "true-to-life" audio excerpts made by playing and recording "real" instruments (by yours truly). In the technical sense, the music was recorded direct to hard disk in Apple Logic Pro 8 software in CD quality audio[32]. The balance between the instruments was adjusted so that all three elements (harmony, bass, and rhythm) were clearly represented in the mix. In addition, some harmonic distortion was added to the bass track (a standard procedure when mixing popular music), in order to make sure that the actual pitches played by the electric bass would be perceived without a shadow of doubt – even with audio reproduction systems with limited low frequency response (such as computer speakers). The instrument tracks were then equalized (in order to get rid of unwanted low frequency rumble) and compressed (in order to reduce the dynamic content of the instruments) – both standard procedures

[32] With a bit depth of 16 bits, and a sample resolution of 44.1 kHz.

in pop music mixdown. Finally, the mix was "normalized"[33] and "bounced"[34] into stereo audio files in MP3 format[35]. The 324 audio files, at 224 KB in size each, amounted to a total of 70.9 MB of hard disk space on the computer.

In the musical sense, on the other hand, the drum kit provided the rhythmic backbone, on top of which elements of harmony (provided by a steel-string acoustic guitar) and chord roots (provided by an electric bass guitar) were layered. The drum beat was a standard pop/rock pattern in 4/4 time[36], remaining unchanged and uninterrupted during the course of the sequence. The strummed guitar chords conformed to the rhythmic pattern of the drums, as did the electric bass accompaniment – the only point of departure being measure four where the guitar and the bass shared a moment of "tacet" (as in "silence") before launching into the Pop Chord Set chords under study.

Table 6.
Structure of stimuli used in the experiment.

	Context (key of **C** major)				**Probe**			
Chord	C	F G	C	(N/C)				
Degree	I	IV V	I	-	X (prime)		Y (target)	
Function	T	S D	T	-				
Measure	1	2	3	4	5	6	7	8
Time*	1739 ms	3478 ms	5217 ms	6957 ms	8696 ms	10435 ms	12174 ms	13913 ms

Legend: (N/C) = No Chord, T = Tonic, S = Subdominant, D = Dominant

* *Elapsed time at the end of each measure. One measure equals approximately 1.74 seconds.*

In regard to the structure of the stimuli, a sense of key[37] was first established by a four-measure perfect cadence (later referred to as "context") in the key of **C** major, followed by a two-chord four-measure progression (later referred to as "probe", and labeled as chords "X" and "Y", or "prime" and "target", respectively). The probes were made up of all possible permutations of the 18 Pop Chord Set chords, resulting in 324 (18^2) unique stimuli, the context being the only shared harmonic entity between the audio excerpts. The clips were recorded – and played back – at a tempo of 138

[33] Bringing the peak sound level close to the digital maximum of 0 dBFS – in this case up to -0.1 dBFS (decibels relative to full scale).
[34] Converted and dithered.
[35] The "MPEG-1 Audio Layer 3" format – in this case at 128 kbps quality.
[36] Arguably the most common meter in popular music.
[37] According to Krumhansl (2000), the tonic (I) and dominant (V) – sometimes along with the subdominant (IV) – are considered most important when establishing the key.

BPM[38] (quarter notes – or beats – per minute), making a single eight-measure stimulus clock in at approximately 14 seconds (see *Table 6* above for a visualization).

The chord voicings used were the most common open position voicings on the guitar, affectionally often referred to as "Cowboy Chords". These chords were played in the middle register[39]: the top notes of the voicings hovering around "g^1"[40], a perfect fifth above middle "*c*". The top notes were kept within a range of (+/-) minor third, in order to facilitate reasonably smooth voice leading. In other words, the top notes of the chords – if the pitch class "*g*" was out of the question – would move to the nearest available chord tone. All in all, great care was taken in order to comply to the basic voice leading rules proposed by Huron (2001). This was somewhat difficult at times, because the clips were recorded one chord at a time, so that a snippet containing a recording of a certain chord could be used on all the other stimuli containing that very chord. In the end, after careful consideration, the stimuli ended up sounding quite natural and coherent, although they were patched together from multiple snippets of audio.

3.3.4 Procedure and apparatus

At the beginning of the first of the two listening sessions, the participants were instructed to fill in a background information questionnaire (see *Table 19* in *Appendix C* for a closer view). After that, they were briefed on the structure ("Cadence > X > Y" or "Key Context > Probe"), number (162 per session), and length (approximately 14 seconds each) of the stimuli. Finally, they were asked to rate the prevalence of chord X resolving into chord Y in the preceding key context (**C** major) on a five-point scale (-2 = very rare … +2 = very common) – and do it 162 times in succession during the session, of course. At this point, the participants were also instructed to keep the applicable music genre (popular music) in mind while providing the ratings. The stimuli were then played back one by one. After each stimulus, playback was paused, and the subjects were given two seconds to respond (see *Table 20* in *Appendix C*), after which the number of the next example was called out loud, and playback was resumed again.

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[38] Twice the average human heart rate of 69 bpm (the mean of means of "at rest" and "during light dynamometry" conditions), as reported in Moser et al. (1994).

[39] According to Terhadt et al. (1982), pitches near the center of the music range are more salient than pitches at the extremes of that range.

[40] When we look at the diatonic chord extensions (9, 11, and 13) of all the diatonic chords in the key of **C** major, the pitch class "*g*" prevails. In addition, most studies on tonal hierarchies agree that the fifth degree pitch class (the dominant or 5) is the second most salient pitch class in any major key – right after the tonic (or 1) of the key. In this study, it was important to keep the chord voicings as neutral as possible. This is why "*g*" – or the nearest chord tone – was on the top on all the chord voicings used. After all, according to Huron (1989), the inner voices are less noticeable that the outer voices (the top note and the bass note).

The playback system consisted of an Apple MacBook Pro computer running Apple iTunes software connected to a Dynacord PowerMate 600 powered mixer and two JBL SRX715 speakers configured in (2.0) stereo with high frequency drivers ("tweeters/horns") vertically aligned with the listeners' ears. No audio processing (i.e. equalization or dynamics processing) was utilized – neither in the software, nor in the hardware. The examples were played back at a "normal" and "comfortable" listening volume collectively agreed upon at the beginning of each listening session.

3.3.5 Experiment design

Because the experiment took place during the spring semester of school year 2009, the listening sessions had to be made to fit the participants' study schedule and the classroom booking system, both of which were made up of standard 45-minute blocks. To meet these requirements, the following schedule was created and utilized:

Table 7.
Structure of listening session 1.

Subject	**Multiplier**	**Minutes**	**Per row total**
Introduction & instructions	1	1	1
Questionnaire	1	1	1
Stimuli ("play")	162	0.233 min (14 s)	37.8 min (37 min, 48 s)
Ratings ("pause")	162	0.033 min (2 s)	5.4 min (5 min, 24 s)
		Total:	**45.2 min (45 min, 12 s)**

Table 8.
Structure of listening session 2.

Subject	**Multiplier**	**Minutes**	**Per row total**
Instructions (recap)	1	1	1
Stimuli ("play")	162	0.233 min (14 s)	37.8 min (37 min, 48 s)
Ratings ("pause")	162	0.033 min (2 s)	5.4 min (5 min, 24 s)
Thank-yous and rewards*	1	1	1
		Total:	**45.2 min (45 min, 12 s)**

** As a goodwill gesture, the participants were treated to assorted Mars, Inc. products – Mars and Twix chocolate bars, to be exact – after having completed the experiment.*

Each participant returned their answer sheets (with the questionnaire fully, and ratings halfway completed) after the first listening session, after which the sheets were stapled together (per participant), and the participant's name was written on the (blank) top sheet in order to avoid confusion. In addition, the sequential number of the listening session was written on the questionnaire sheet. When the participants returned to their personal second, and final, listening session, the stack of sheets was handed back to them for completion. After the experiment was succesfully completed, the top sheet (with only the participant's name on it) was torn off to adhere to the promised full anonimity.

3.4 Data analysis

When the listening sessions were over, the answer sheets were first checked for imperfections, such as nonexistent or unclear markings (delightedly there were none to be found). Next, a spreadsheet document, containing columns for the participants and rows for their questionnaire replies and listening experiment ratings, was created. The data was then entered into the spreadsheet one participant at a time. In order to facilitate the (tedious) entering process, the ratings were first entered using single integers (on a scale of 1 to 5), so that each value could be entered with a single keystroke. The values were later converted to the final scale of -2 to +2 by using the find-and-replace function of the software.

After all the data collected had been entered into the spreadsheet, standard descriptive statistics – such as arithmetic *means*, average and standard *deviations*, and *kurtosis* – were calculated on a row by row basis, in order to have a first analytical look on the data. Signs of unusually high deviations and/or kurtosis values were searched for. The average deviation was in the .27 – 1.20 range, and standard deviation in the .40 – 1.41 range on a five-point scale. This was considered as being nothing out of the ordinary. The kurtosis was in the -2.12 – +6.42 range, with only 13 out of 324 instances with a kurtosis of over +3.00. The instances with a higher kurtosis than +3.00 were manually examined by entering the arithmetic mean of the answers in place of the "peaked" ratings causing high kurtosis. In the worst case (the stimulus with a kurtosis of +6.42), removing the peakedness resulted in a +.05 change in the arithmetic mean, so the kurtosis levels were deemed as not posing a great threat to the general reliability of the data.

The actual results of the experiment – the means of the participants' stimulus-by-stimulus ratings – will be examined in detail in the next chapter.

Chapter Four: Results

In this chapter, the results of the experiment will be presented. We will begin by looking at some key correlation figures. First, the ratings given by the participants are put up with each other, in order to see if their responses correlate. If subjects with virtually no positive intersubject correlation are found, their contributions will be removed from the data set. Next, the subjects are organized in groups, based on their main instrument and the extent of their formal music education. The between-group correlations of these two variables are then extracted from the data and discussed. After the information provided by the background information questionnaire is dealt with, we will finally move on to the main results of the experiment, namely the chord pair resolution prevalence data. At the end of the chapter, the results of the experiment are compared to an established model of harmonic hierarchy.

4.1 Cross-subject correlation

A correlation matrix for the 21 participants' ratings of all ($18^2 = 324$) chord pairings was created. One participant (originally abbreviated as "pp015") had two instances of no correlation with other participants, and a relatively low average correlation level (r = .226), so was removed as an outlier. The mean of the cross-subject correlation of the remaining 20 participants was .396 with no negative or practically insignificant (r = 0.0–0.1) values between any pairs of participants. Rough cross-subject correlation levels can be seen in *Figure 3* (below). For a detailed view on cross-subject correlations, please refer to *Table 21 in Appendix D*.

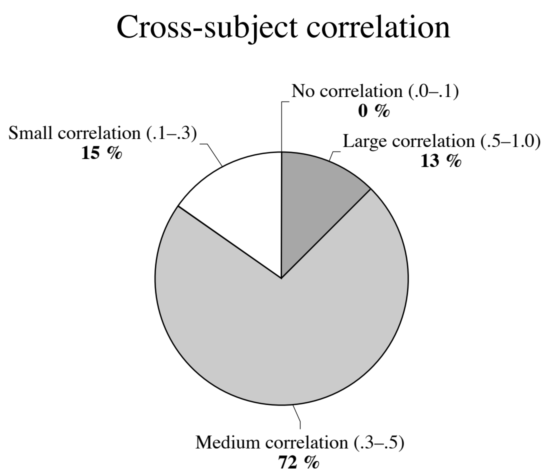


Figure 3. Cross-subject correlation of participants.

4.2 Between-group correlation: Main instrument

Based on my 18 years of experience in teaching theory, harmony and ear training to students ranging from basic education through upper secondary level and all the way up to higher education, students of harmony instruments, such as the guitar or the piano, have always fared well in the aforementioned subjects. Many vocalists (melody) and drummers (rhythm), on the other hand, have had their share of difficulties in traditional music school tasks in music perception. With this background in mind, I was interested to see whether the participants' choice of main instruments would have an effect on their responses.

Firstly, the participants were grouped in three groups (Melody, Harmony and Rhythm) based on their main instrument. Naturally, none of the participants – being students of music – had chosen the "I don't play or sing" option, so it was left out of the equation. Secondly, the means of the participants' responses were calculated in order to gain one set of (mean) values as a single variable for each group, so that between-group correlation could be measured. Thirdly, the Pearson correlation coefficents for the three groups were calculated, and a correlation matrix (see *Table 9* below) was generated.

The between-group correlations were all strong (r = .711 – .846) and significant (p = .000), as can be seen in *Table 9*. Compared to the other two groups, harmony instrumentalists possessed the highest correlation ratings ($\bar{x}_r$ = .816), followed by melody instrumentalists ($\bar{x}_r$ = .779) and finally rhythm instrumentalists ($\bar{x}_r$ = .748), suggesting that in this case, harmony instrumentalists may best – although by a small margin – represent the other instrumentalists' responses.

Table 9.
Between-group correlation (Pearson) for variable "Main instrument" (Melody, Harmony and Rhythm).

	Melody	Harmony	Rhythm
Melody	1		
N	-		
P	-		
Harmony	**,846**	1	
N	324	-	
P	,000	-	
Rhythm	**,711**	**,785**	1
N	324	324	-
P	,000	,000	-

The standard deviation in the responses of harmony instrumentalists was the lowest (s = .783) followed by melody instrumentalists (s = .809) and rhythm instrumentalists (s = .868), the total range of values in responses being 4.0 (-2 – +2). This result supports my original assumption about harmony instrumentalists' ability to process musical perception tasks somewhat "better" (as in "firm", "precise" or "accurate") than other instrumentalists. As a peculiar side note, harmony instrumentalists gave consistently lower fitness ratings ($\bar{x}$ = .206) for chord resolutions presented to them than rhythm or melody instrumentalists ($\bar{x}$ = .374 and $\bar{x}$ = .425, respectively). This may indicate that harmony instrumentalists are more critical compared to the others in judging the appropriateness of harmonic progressions, because of their well-versedness in (tonal) harmony.

4.3 Between-group correlation: Formal music education

All the participants had attended formal musical education for between one to twenty years. I split the participants in two groups to see if their responses would vary depending on their education history. I created one group for students with 1 to 10 years of formal music education (n = 11), and another for students with 11 to 20 years of studies (n = 9). The Pearson correlation coefficent for the groups was strong and significant (r = .863, p = .000), suggesting that the extent of prior musical education does not have a significant effect on the participants' responses. This result supports and adds up to the previous studies (Cuddy & Badertscher, 1987; Koelsch et al., 2000; Koelsch et al., 2003; Krumhansl, 1990; Krumhansl, Bharucha, & Kessler, 1982; Regnault, Bigand, & Besson, 2001; Tillmann, 2008; Tillmann, Bharucha, & Bigand, 2001) suggesting that the fundamental features of the tonal-harmonic system are *learned* by simply being exposed to music in everyday life, and thus not in music schools or the like, although the neural processes underlying the generation of the early right anterior negativity (ERAN) have been shown to be *modifiable* by formal musical long-term training in Koelsch et al. (2002).

4.4 Pop Chord Space

The majority of the questions (324 out of 328) presented to the participants during the experiment were naturally dedicated to the main research question of "How common is it for chord X (or *prime*) to resolve into chord Y (or *target*) in the given contexts (key context: **C** major; genre context: popular music)?". The subjects were asked to rate the prevalence of the resolutions on a five-point scale with "-2" representing *very rare*, and +2 *very common*.

4.4.1 Chord prevalence ratings

The means of the participants' ratings were merged into a 18^2 chord matrix, presented in *Table 10* (below). In this very table, a formerly static list of chords (the Pop Chord Set) with no deeper meaning, begins, for the first time in this study, to gradually transform into a dynamic and hierachical representation of popular music harmony, affectionately – and provocatively – called "Pop Chord Space".

Note that the table is read from the left (prime, *y* axis) to the top (target, *x* axis), with the mean rating residing at the crossing of the axes. Also, it is worth noting that all the prevalence ratings (including their means, of course) from this point on are presented using the same -2 to +2 scale.

Table 10.
Chord resolution prevalence rating matrix (displayed with arithmetic means calculated from the participants' responses).

	C	**d**	**e**	**F**	**G**	**a**	**G7**	**A7**	**B7**	**C7**	**D7**	**E7**	**c**	**Eb**	**f**	**g**	**Ab**	**Bb**
C	1,20	1,20	1,05	1,50	1,65	1,85	0,80	0,85	0,00	1,10	0,75	0,55	-0,25	0,75	-0,05	1,10	0,85	1,00
d	1,30	1,05	0,00	1,20	1,35	1,60	1,05	0,90	-0,65	-0,75	0,15	-0,10	-0,70	0,20	-0,55	0,45	-0,60	1,10
e	0,55	-0,10	0,70	0,80	0,90	1,40	0,50	1,60	0,35	-0,50	-0,20	0,35	-1,05	0,25	-0,90	-0,40	-0,15	0,00
F	1,65	1,50	0,50	1,00	1,50	1,10	1,30	0,45	-0,90	0,20	0,80	0,20	0,10	0,75	0,35	0,60	1,10	0,90
G	1,25	1,10	0,50	1,45	1,20	1,50	0,95	1,05	-0,10	-0,15	0,35	0,55	-0,65	0,10	-0,50	0,05	0,35	1,15
a	1,40	0,90	1,35	0,95	1,30	1,45	0,60	0,20	-0,05	-0,50	1,10	1,00	-1,05	-0,35	-0,20	-0,90	0,45	0,55
G7	0,75	1,10	0,10	1,05	0,95	1,20	1,05	0,20	0,05	0,40	0,65	-0,20	-0,35	0,75	-0,70	0,00	0,55	1,00
A7	0,80	1,10	0,40	0,50	0,85	0,25	0,50	0,80	-0,05	-0,35	0,65	0,05	-1,35	-0,55	-1,00	-0,65	-0,25	0,40
B7	0,30	-0,70	0,75	-0,50	-0,25	0,00	-0,35	0,25	0,50	-0,55	0,20	0,35	-1,35	-0,35	-0,85	-0,80	-0,65	0,05
C7	-0,40	0,30	-0,35	1,30	0,60	0,25	0,45	0,20	-0,95	0,85	0,15	-0,35	-0,60	0,75	0,15	0,20	0,45	0,85
D7	0,65	-0,20	0,15	1,05	0,80	1,05	0,70	-0,60	-0,40	-0,20	0,55	-0,55	-1,55	0,10	-0,50	0,10	-0,75	0,40
E7	0,30	-0,30	-0,45	1,05	0,55	1,60	0,10	1,30	-0,35	-0,75	-0,15	0,65	-1,65	-0,70	-0,85	-0,95	-0,55	-0,20
c	0,15	-0,55	-0,55	1,10	0,85	-0,70	0,60	-0,85	-1,00	0,10	-0,05	-0,85	0,75	1,35	0,85	1,35	1,00	1,35
Eb	0,85	0,00	-1,25	1,50	1,05	-0,90	0,70	-0,45	-0,80	0,85	0,10	-0,80	0,70	0,75	0,00	1,15	0,90	1,55
f	1,20	-0,05	-0,95	0,55	0,15	0,00	0,20	-0,50	-1,20	0,30	-0,25	-0,20	1,05	1,20	0,30	-0,05	0,90	1,35
g	1,15	1,40	-0,55	0,90	0,45	-0,45	0,30	-0,20	-0,80	0,45	0,10	-0,35	0,45	0,90	-0,95	0,45	0,55	1,20
Ab	1,20	-0,60	-1,30	1,05	0,25	-0,70	0,25	-0,55	-0,80	0,10	-1,00	-0,90	1,40	1,25	1,15	0,50	1,05	1,65
Bb	0,70	0,80	-1,10	1,55	1,05	0,55	0,55	-0,10	-0,75	0,05	0,15	-0,50	0,50	1,25	0,70	0,95	0,50	0,85

Note. Primes along the *y* axis (leftmost column) – targets along the *x* axis (topmost row). Minimum value = -2 ("very rare") – maximum value = +2 ("very common").

The data presented above (*Table 10*) single-handedly gives answers to two of the three principal research questions: *1)* "What are the chords that a certain chord is likely to resolve into in a popular music context?", and *2)* "What is the prevalence of these resolutions?". However, this study would be a torso without further elaboration.

The ratings of *Table 10* are viewed from two different angles on a chord-by-chord basis in *Appendix E*[41]: first, the ratings given when the chord in question was serving as a *prime* (chord "X") within the probe (chord pair "X > Y") that was presented after the key context, and second, the ratings given when the chord in question was serving as a *target* (chord "Y"). The "prime condition" ratings (the topmost chart in the figures presented in *Appendix E*) answer to the questions of "Into what chords is the chord in question likely to resolve into in the given key context?", and "How likely are these resolutions?". The "target condition" ratings (second chart from the top), on the other hand, answer to the questions of "What chords are likely to resolve into the chord in question in the given key context?", and, again, "How likely are these resolutions?".

[41] The graphical representations resulting from this shift in perspective are displayed in an appendix (separately from the text) because of their substantial size.

The "valid" resolutions (i.e. resolutions with a positive rating[42]) are separated in the charts with a dashed line, with the valid ones residing on the left side of the line. For example, if we take the *first two* charts of the first figure (*Figure 18*) of *Appendix E*, representing the behavior of the "C" major chord in the key context of **C** major (and within the genre of popular music), the following conclusions can be drawn by reading the charts provided:

- The "C" major chord is most likely to resolve into the "a" minor chord, and least likely to resolve into the "c" minor chord.
- The valid resolutions of the "C" major chord are all the chords of the Pop Chord Set, excluding the chords "B7", "f", and "c".
- The chord most likely to resolve into the "C" major chord is "F" major, and the least likely "C7".
- The valid chords to resolve into the "C" major chord are all the chords of the Pop Chord Set, excluding the chords "B7", "E7", "c", and "C7".

4.4.2 Chord directionality

Now, if we take the mean ratings of a single chord in both prime ("X") and target ("Y") conditions (as described above), and combine them into a single chart (second from the bottom) – again on a chord-by-chord basis – we will get a representation of the *directionality* of the chord in question (the bottommost chart). The directionality value is simply the difference between the prime and target condition ratings of a certain chord. If the difference is small (or nonexistent, like is the case with two identical chords), the chord pair in question is rather nondirectional, meaning that the chords are used adjacent to each other disregarding their order. If, on the other hand, the difference is large, the chords are used in one orientation only. For example, if we take the *last two* charts of the first figure (*Figure 18*) of *Appendix E*, representing the behavior of the "C" major chord in the key context of **C** major (and within the genre of popular music), the following conclusions can be drawn by reading the charts provided:

- The "C" major chord is the most directional when combined with the chord "C7". In other words, the chord progression "C > C7" can be regarded as being quite common, but when in reverse ("C7 > C"), the progression becomes rare.

[42] As in "closer to 1 (somewhat common) than 0 (neutral or "I Don't Know"), or greater" – in other words: ≥ .50.

- The "C" major chord is the least directional when combined with the chord "g". In other words, the chord progressions "C > g" and "g > C" can be regarded as being equally common (or rare).

These directional features constitute a fascinating, but, to my knowledge, rarely studied account of tonal-harmonic hierarchies. Upon preliminary inspection, these directionality values seem to correlate positively with my practical experience in tonal music, but, unfortunately, an in-detail investigation of these features is beyond the scope of this study.

Note that the all the interpretations presented above apply to all chords presented in *Appendix E*.

4.4.3 Target ratings by chord function and quality

Inspired by Krumhansl (1990), I wanted to find the most likely target chords by grouping the mean ratings by both target chord *function* and *quality*. In *Table 11* (below), the means are calculated in reference to two conditions: the targets have been primed with (or, in other words, preceded by) *1)* all 18 Pop Chord Set chords, and *2)* the tonic chord only. The tonic chord priming condition can be seen as best representing the majority of the previous studies using *tonic chords*, *diatonic scales*, and/or *cadences ending on the tonic* as primes and/or contexts.

Table 11.
Target chord prevalence ratings – grouped by target chord function and quality. Primed with the Pop Chord Set ("PCS") and the tonic chord only ("I").

Target chord function	PCS	I	Target chord quality	PCS	I
Diatonic triad	.61	1.41	Major	.72	1.16
Secondary dominant	.10	.68	Minor	.11	.82
Modal interchange	.22	.57	Dominant seventh	.10	.68

Krumhansl (1990) wanted to find out whether diatonic triads received higher ratings than those which included nondiatonic pitch classes. The correlation between chord fitness and diatonicity was found only moderately stong, until a masking effect of triad type[43] was eliminated. In the end, diatonic triads were found to receive higher ratings than nondiatonic triads of the same type (Krumhansl, 1990). Krumhansl's coarse classification scheme (diatonic vs. nondiatonic) has been replaced here with a finer approach. Although the rating scales, classification schemes, and chord types[44] are somewhat different in the two studies, they both exhibit a similar tendency of favoring diatonic target chords over nondiatonic ones (see the left hand side of *Table 11* above). Note that these findings may be in conflict with the generally accepted view (see Nettles & Graf, 1997) of

[43] Masking the relationship between the ratings and the binary (diatonic vs. nondiatonic) classification.
[44] Krumhansl (1990) compared triads – in this study, a mixture of triads and seventh chords is used.

considering dominant chords as permanent residents of the rhythmically weak beats and/or measures – after all, the target chords occupied the rhythmically weak portion of the stimuli in the present study, and the lowest target ratings are those of the dominants. Unfortunately, this hypothesis cannot be examined with the current set of data, because fitness (or prevalence) ratings of the primes – chords in a strong rhythmic position, that is – were not requested from the subjects in the first place. All in all, this dilemma should benefit from further investigation.

In addition to chord function, the target chord prevalence ratings were also grouped by chord quality, to see whether the listeners would give higher ratings to chords of a given sonority type. As in the Krumhansl (1990) study, the order of preference was major first, then minor, and finally the third chord quality examined – in this case the dominant seventh chord, and the diminished triad in the Krumhansl study. Note how the margin by which the major chord type dominates the others is wider when the target is primed with all Pop Chord Set chords. This property tells us that it is quite common to proceed from the tonic (prime) to virtually any (Pop Chord Set) chord quality, but a resolution to a major chord quality is preferred over other options *in general* (i.e. if the prime is any of the other Pop Chord Set chords – other than the tonic, that is).

4.4.4 Target ratings by prime chord function and quality

If we take the means of means of all Pop Chord Set target chord prevalence ratings, and prime them one by one with each Pop Chord Set chord, we will end up with ratings describing which (prime) chords have the most paths open, and which ones the least – or, to be exact, which chords have a tendency to resolve into highest rated chords, and which ones into the lowest rated ones. As can be seen in *Figure 4* (below), chords primed with the basic diatonic functions of I, IV, and V (including the V7) have the highest prevalence ratings. This can either mean that the primary chord functions have the most paths open, or they are consistently resolved into chords with higher-than-average prevalence ratings. Furthermore, if we follow the logic presented earlier, and group these target ratings together by prime chord function and quality, we will arrive at the figures presented in *Table 12* below.

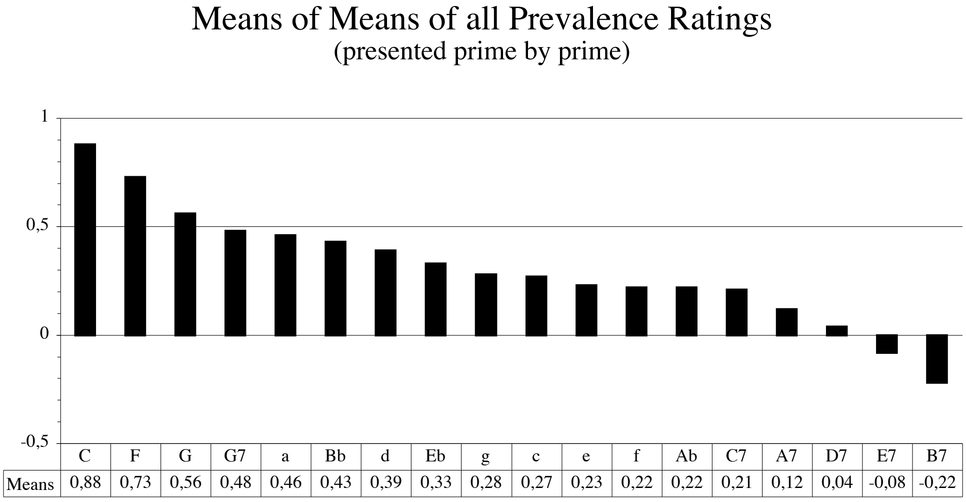


Figure 4. Means of means of all Pop Chord Set prevalence ratings, presented prime by prime.

Table 12.
Target chord prevalence ratings – grouped by prime chord function and quality.

Prime chord function	**Target means of means**	**Prime chord quality**	**Target means of means**
Diatonic triad	.54	Major chord	.53
Secondary dominant	.09*	Minor chord	.31
Modal interchange	.29	Dominant seventh	.09

** If the "G7" chord is included in the diatonic set, this value drops down to .02.*

In sum, these results suggest that diatonic chords and, on the other hand, major chords, have the most paths open after them[45], followed by the modal interchange (and minor) chords, and finally the secondary dominants (and dominant seventh chords in general).

4.5 Pop Chord Space vs. Tonal Pitch Space

As noted earlier, tonic chords, diatonic scales, and/or cadences ending on the tonic are used as key contexts in most of the experiments presented in studies that focus on harmonic hierarchies. Although the subjects of this study were asked to rate the *prevalence* of certain prime-target resolutions, the ratings can be seen as being closely related to ratings of target chord *harmonic hierarchy*. In other words, if a chord resolution is perceived as being *common* in a given key context, you could imagine this common target being perceived as having a high *fitness* rating in relation to the prevailing key. In order to make the ratings of the current study compatible with other studies on harmonic hierarchies, three adjustments need to be made – one in regard to the content, and two minor semantic changes. First, since the earlier studies have almost exclusively used tonic sounds as key concepts and/or primes, we will have to exclude all (17) other primes than

[45] Or, as stated earlier, are consistently followed by chords with higher-than-average prevalence ratings.

the tonic from the results of this experiment – for now. In other words, for the time being, we will be looking at the ratings on the second row (row "C") of *Table 10* presented earlier. Second, we will call the prevalence ratings *fitness* ratings from now on – just to shift our mindsets a little towards harmonic hierarchies. Third, we will call this rediscovered hierarchy "Pop Chord Space" for reasons you will soon find out.

4.5.1 Tonal Pitch Space

The second hypothesis of this study was "It is expected that the internal hierarchy of this default chord set [Pop Chord Set, as it was named later] correlates positively with one (or some) of the models of harmonic hierarchy proposed in prior scientific studies…". The four studies presented earlier in the literature review (*Subchapter 2.2: Previous studies on tonal hierarchies*) were scrutinized with possible correlation measurements in mind. In the end, only one one of them turned out to be worth closer inspection. First of all, neither the roughness values of Hutchinson & Knopoff (1978), nor the pitch commonality values of Parncutt (1989) were octave generalized, so they had to be discarded right away. Next, Krumhansl's (1990) model of harmonic hierarchy had only eight chords in common with the 18 chord classes of the current study, so it would not have been of much help. After these disappointments, the only option left was the Tonal Pitch Space model by Lerdahl (1988). Luckily, the model was soon found to fit the purposes of this study perfectly, because with the model, it is possible to compute the psychological distance of practically any two chords.

(Note that, as discussed earlier, Lerdahl's (1988) model was later expanded to discriminate between triads and seventh chords by Bigand et al. (1996), so any reference made to Tonal Pitch Space from now on refers to the 1996 version.)

In order to be able to directly compare the ratings obtained from the listening experiment (Pop Chord Space) with the distance values provided by the Tonal Pitch Space model, the values had to be converted to conform to the same metric. Bigand et al. (1996, p. 129, Table 1) had already computed the Tonal Pitch Space distances (from the tonic) for 50 chords. The range of their values was from 0 to 24, including integers only, so the total number of unique values was 25. Because their most distant chord received the highest rating, the values had to be inverted first, so as to comply to the ratings of the present study (a five-point scale from -2 to +2, with the lowest ratings reserved for chords with the lowest perceived fitness). Now, with the same direction in both of the value sets, it was quite easy to convert the values from the 25-point scale of the Tonal Pitch Space over to the 5-point scale of the Pop Chord Space.

Tonal Pitch Space distances are usually presented in a rather un-intuitive and unmusical manner. For example, in the Bigand et al. (1996) revision, chords are grouped together in a table by chord quality, and then listed below each other with their roots ascending chromatically. This, by no means, bears any resemblance to the actual musical practice, and that is why the most important values in the table – the actual pitch distances – seem to be arranged randomly. After noticing this, I started to explore different methods of visualizing chord and/or key relationships in a simple and graphical way. At first, I revisited the key relation maps of Weber, Schoenberg, and Krumhansl and Kessler (see *Figures 1* and *2,* respectively). In the end, they were all too multi-dimensional for the task at hand. The solution needed to be two-dimensional, so that the chords could lie on the horizontal plane, and be positioned at the bottom of a line chart, for example. Enter neo-Riemannian transforms.

4.5.2 Neo-Riemannian transforms

At the turn of the 19th and 20th centuries, Hugo Riemann laid the groundwork for a generation of theorists, with David Lewin as their front runner in the 1980s (Cohn, 1997;1998). Neo-Riemannian theory[46] originated in Lewin's transformational approach to triadic relations, presented in his 1982 essay, "A Formal Theory of Generalized Tonal Functions" (Cohn, 1998). The essay introduced two classes of transformations: the first[47] maps major and minor triads together by inverting a triad – the second, on the other hand, arranges pitch classes in a line of alternating minor and major thirds with each contiguous triplet constituting a triad (Cohn, 1998) (see *Figure 5* below).

Gb	bb	Db	**f**	**Ab**	**c**	**Eb**	**g**	**Bb**	**d**	**F**	**a**	**C**	**e**	**G**	b	**D**	f#	**A**	c#	**E**	g#	**B**	d#	F#

Figure 5. Pitch classes in a line of alternating minor and major thirds – in this case, represented as major and minor triads (adapted from Cohn, 1998). Note that the chords belonging to the Pop Chord Set are presented in boldface.

This representation suited the needs of this study: it was two-dimensional and linear. Like the toroidal map of key relations by Krumhansl & Kessler (1982), this model is able to convey some important information on tonal-harmonic hierarchies: the circle of fifths and the *relative* major-minor key relations are both represented clearly – the only element missing being the *parallel* major-minor key relations, which are impossible to visualize without adding extra dimensions to the model. In this study, the model described above is modified in two respects. First, the *nondiatonic*

[46] According to Cohn (1998), Neo-Riemannian theory was created in response to analytical problems posed by chromatic music that is triadic but not tonally unified (e.g. music by Wagner & Liszt).

[47] According to Cohn (1997), there are three operations, abbreviated PLR, that maximize pitch-class intersection between pairs of triads: P (parallel), relating triads that share a common fifth; L (Leading-tone exchange), relating triads that share a common minor third; and R (relative), relating triads that share a common major third.

major triads to the right of the center ("C") are replaced with the respective dominant seventh chords. These "sharp" (compared to the key) major triads are virtually non-existent in non-dominant function – with the exception of a rare occasion of "II" (or "D" in the key of **C**) as a Lydian modal interchange chord (see Johansson, 1990, for its application in the harmonic language of The Beatles). Second, the nondiatonic minor triads to the right of the center ("C") are removed from the model altogether, because they are practically never heard in tonal music – the only exception that I have run across being the "vii" (or "b" in the key of **C**) as the second chord in *Yesterday* by The Beatles.[48] With these modifications, the model (presented in *Figure 6* below), in my opinion, better represents the practice of tonal harmony in practice (pun intended).

Gb	bb	Db	**f**	**Ab**	**c**	**Eb**	**g**	**Bb**	**d**	**F**	**a**	**C***	**e**	**G***	**D7**	**A7**	**E7**	**B7**	F#

Figure 6. Chord relations in a line (adapted from Cohn, 1998, and modified for the purpose of this study to include secondary dominants). Note that the chords belonging to the Pop Chord Set are presented in boldface. Also note that the far ends of the model (Gb/F#) are interconnected.

* *The dominants missing from the figure (C7 and G7) will be added right next to these diatonic chords later.*

4.5.3 Pop Chord Space and Tonal Pitch Space correlation

With the results of the two studies on the same metric, it was possible to compare them side by side. First, a Pearson correlation coefficent was computed for the two models. The observed correlation was found moderate at .488 (n = 18, p = .040), and statistically significant (*Figure 7*).[49]

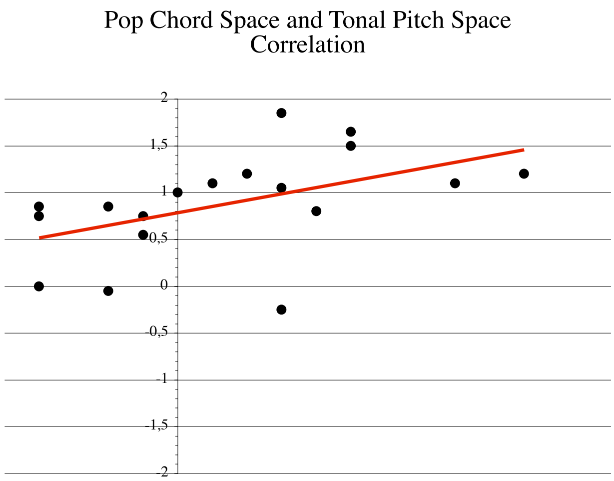


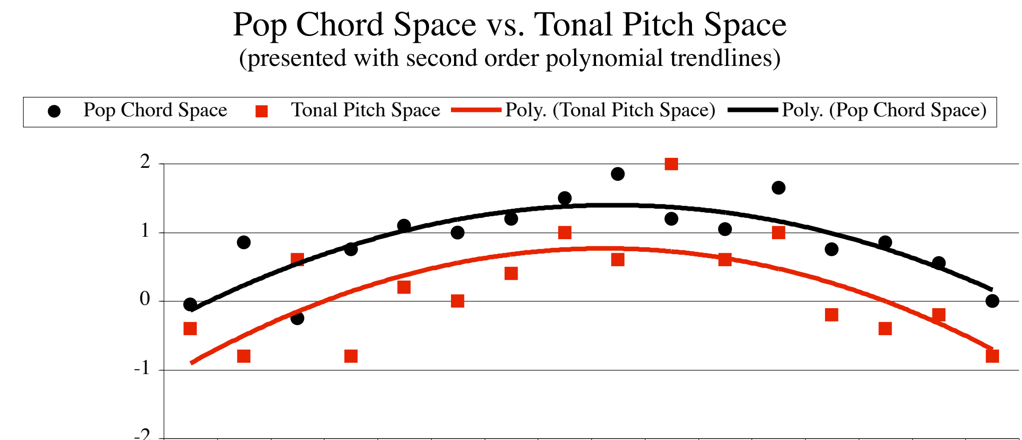
Figure 7. Pop Chord Space and Tonal Pitch Space correlation.

Next, the fitness ratings of the present study and the distance ratings from the Bigand et al. (1996) study were entered onto a datasheet in the order presented above (see *Figure 6*). By looking at the

[48] Although its function on that particular song is actually a secondary subdominant – not a "vii" per se.

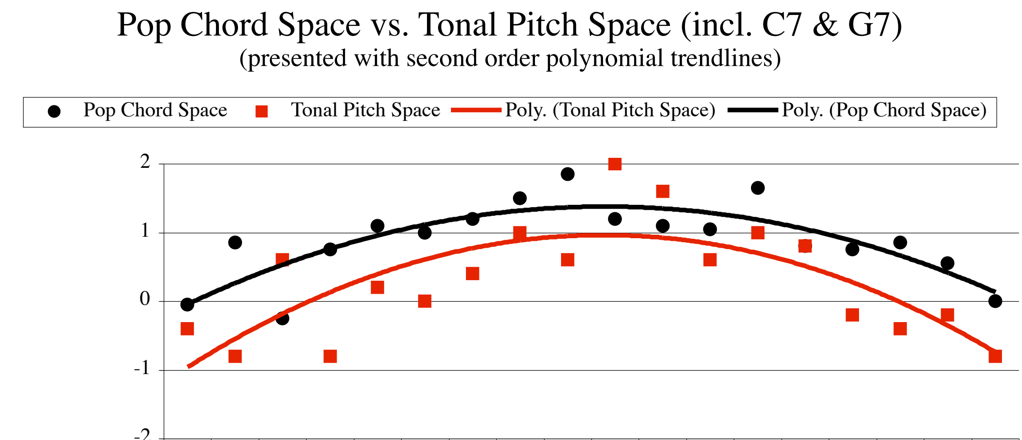
[49] Note that the results of the two studies were only *converted* to the same metric. They were not *normalized* at all, although by doing so, the correlation might get even larger.

plotted values (dots and squares) in *Figure 8* (below), it became clear that there might be a relationship between the two models. This became even more evident when second order polynomial trendlines were added to the graph, in order to visualize the trends lying underneath the figures. At first, it seemed as the trendlines would run parallel to each other all the way through the plot, predicting no drastic difference between the two models (*Figure 8*). When the missing dominants (C7 and G7) were added to the equation next to their corresponding triads, the paradigm started to shift. It became clear that the further away from the tonic the target chord was, the further away the two models were going to be from each other (*Figure 9*). To further investigate this tendency, the models were broken down by chord quality.



	f	Ab	c	Eb	g	Bb	d	F	a	C	e	G	D7	A7	E7	B7
Pop Chord Space	-0,05	0,85	-0,25	0,75	1,10	1,00	1,20	1,50	1,85	1,20	1,05	1,65	0,75	0,85	0,55	0,00
Tonal Pitch Space	-0,40	-0,80	0,60	-0,80	0,20	0,00	0,40	1,00	0,60	2,00	0,60	1,00	-0,20	-0,40	-0,20	-0,80

Figure 8. Pop Chord Space vs. Tonal Pitch Space.



	f	Ab	c	Eb	g	Bb	d	F	a	C	C7	e	G	G7	D7	A7	E7	B7
Pop Chord Space	-0,05	0,85	-0,25	0,75	1,10	1,00	1,20	1,50	1,85	1,20	1,10	1,05	1,65	0,80	0,75	0,85	0,55	0,00
Tonal Pitch Space	-0,40	-0,80	0,60	-0,80	0,20	0,00	0,40	1,00	0,60	2,00	1,60	0,60	1,00	0,80	-0,20	-0,40	-0,20	-0,80

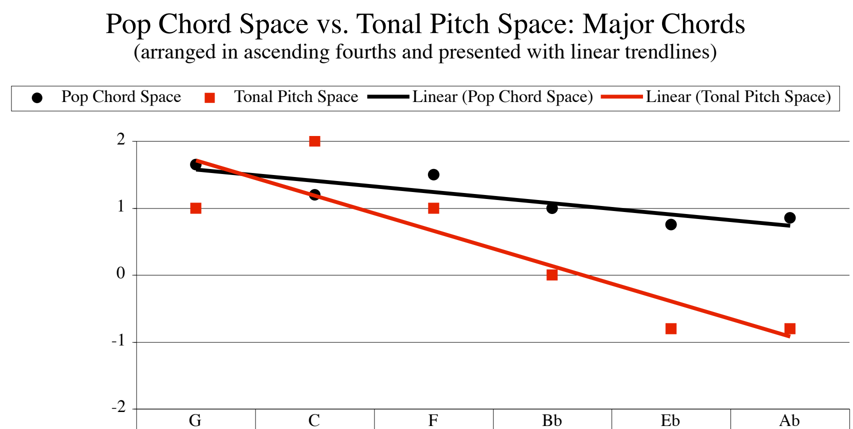
Figure 9. Pop Chord Space vs. Tonal Pitch Space (including C7 and G7).

4.5.4 Pop Chord Space vs. Tonal Pitch Space: breakdown by chord quality

The third hypothesis of this study was "It is expected that the to-be-presented model of harmonic hierarchy in popular music [Pop Chord Space] differs in some aspect(s) from earlier, classical models", and further, "The 'counterclockwise' major chords on the circle of fifths are expected to reside higher in the harmonic hierarchy of popular music". In order to be able to confirm or reject the hypothesis, the data from the previous charts (*Figures 8* and *9*) was split into separate charts, each containing the data of a single chord quality only. The chords were organized in reverse order[50] left to right, to better conform to the standard musical practice of upward resolution by fourths (or, in other words, downward by fifths).

Major chords

As can be seen in *Figure 10* (below), the difference between the two models gets larger the further away from the tonic the major triads reside. This confirms the original hypothesis, as does my practical experience in classical and popular music harmony. To futher generalize, it should be noted that in popular music, it seems that the "flat" (compared to the tonic) major triads are perceived as being "closer" to the prevailing major key than in classical music, represented here by the Tonal Pitch Space model. This view is supported by the fact that the diatonic triads are clearly closer to each other in the two models than the nondiatonic ("flat") ones.[51]



	G	C	F	Bb	Eb	Ab
Pop Chord Space	1,65	1,20	1,50	1,00	0,75	0,85
Tonal Pitch Space	1,00	2,00	1,00	0,00	-0,80	-0,80

Figure 10. Pop Chord Space vs. Tonal Pitch Space: major chords.

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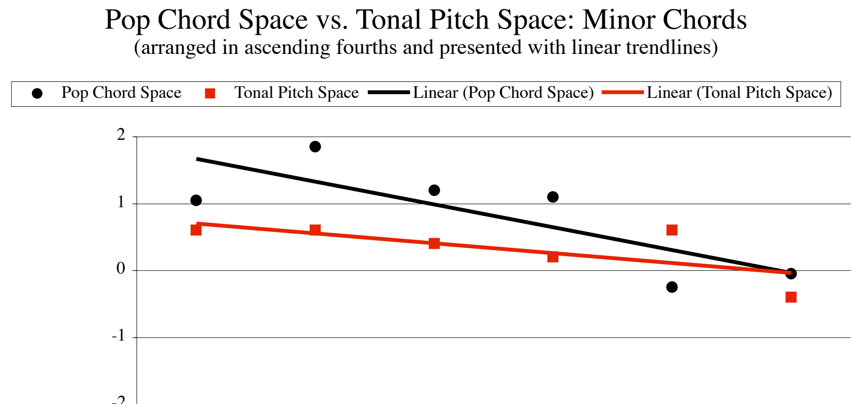
50 According to the reversed circle of fifths, or the standard "cycle of fourths".

51 As a side note, the difference between the tonic ratings, for example, can be traced back to the design principles of the models. The Tonal Pitch Space, in this case, computes psychological distances between chords, and the distance between two occasions of the same chord should obviously be "0", represented here by the maximum rating of "2". Regarding the Pop Chord Space, on the other hand, the fitness of the target chord was measured by rating the prevalence of the resolution in question, which, in this case, is hardly a resolution at all. The "C" to "C" "resolution" cannot be called a progression either, because it is actually nothing but a stasis. Thus, it may have been somewhat confusing for the subjects to rate the "progression" in question, and this may have had an effect on the results.

Minor chords

A similar (but reversed) tendency can be seen in the models when comparing minor chords (*Figure 11* below). I believe that here the Pop Chord Space represents general tonal practice better. For example, based on experimental studies (Krumhansl et al. 1982; Krumhansl, 1990) and music-theoretical presentations (Piston, 1978), the third degree chord ("iii" or "e" in **C**) in a major key can be regarded as being relatively rare in harmonic progressions, and playing the weakest role (along with the "vii°" chord) in defining the key. This view is supported by the Pop Chord Space, but not the Tonal Pitch Space. In addition, the "i" chord (or "c" in **C** major), is considered being rather close to the prevailing key by the Tonal Pitch Space (because they happen to share two out of three pitches), alhough I have never seen it occur in a major context as a genuine and independent (modal interchange) "i" chord, unless it belonged to a modulation.[52] Incidents like this reveal the weaknesses of such models, in that they do not take account of the human aspect of music perception, but, instead, rely on acoustical, mathematical, or music-theoretical properties of separate or, in this case, simultaneous pitches.



	e	a	d	g	c	f
Pop Chord Space	1,05	1,85	1,20	1,10	-0,25	-0,05
Tonal Pitch Space	0,60	0,60	0,40	0,20	0,60	-0,40

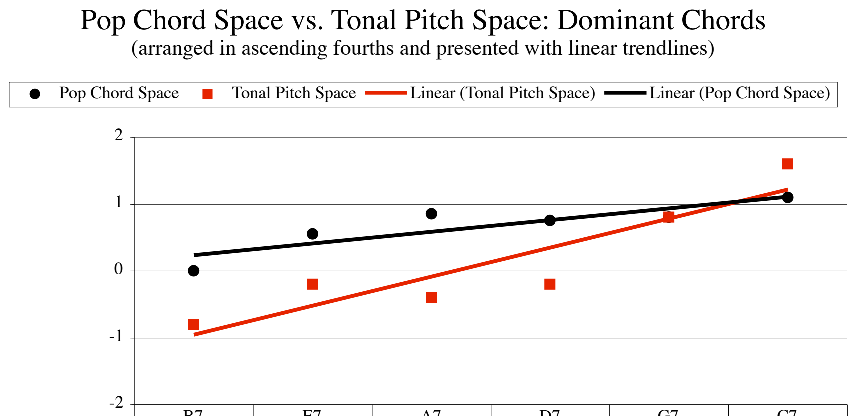
Figure 11. Pop Chord Space vs. Tonal Pitch Space: minor chords.

Dominant seventh chords

Last, but not least, we will look into the behavior of dominant seventh chords. The situation here is practically a mirror image of the major chord case: the difference between the models gets larger the futher away from the tonic the target chord in question is (*Figure 12*). These results also support the arrangement in *Figures 8* and *9* where the two dominants, "I7" and "V7" (or "C7" and "G7", respectively), were placed next to their diatonic triad counterparts. After all, these two dominants

[52] A borderline case being *Wave* by Antonio Carlos Jobim, where the intro of the song (the majority of which is in a major key) is a Dorian modal interchange vamp ("i > IV" or "c > F" in **C** major – or actually in **c** "Dorian minor").

are "closer" to the key center than the others, as is the case with the corresponding triads ("I" and "V", or "C" and "G"), too. To summarize, it seems that secondary dominants – especially when further away from the tonic – are perceived as being "closer" to the prevailing major key in popular music than in classical music, represented here by the Tonal Pitch Space model.



	B7	E7	A7	D7	G7	C7
Pop Chord Space	0,00	0,55	0,85	0,75	0,80	1,10
Tonal Pitch Space	-0,80	-0,20	-0,40	-0,20	0,80	1,60

Figure 12. Pop Chord Space vs. Tonal Pitch Space: dominant chords.

Summary

In sum, the results presented in this chapter suggest that...

- harmony instrumentalists may best – although by a small margin – present the melody and rhythm instrumentalists when evaluating harmonic prevalence and/or hierarchy,
- the extent of prior musical education does not have a significant effect on the participants' ability to rate harmonic phenomena,
- the subjects have a tendency of favoring diatonic target chords over nondiatonic ones,
- diatonic chords and, on the other hand, major chords, have the most paths open after them, followed by the modal interchange (and minor) chords, and finally the secondary dominants (and dominant seventh chords in general),
- the models of harmonic hierarchy compared here (the Pop Chord Space and Tonal Pitch Space, namely) have similar structural rules and tendencies, although...
- the further away from the tonic the target chord is, the further away the two models are from each other, suggesting that there is a perceived difference between harmonic hierarchies of different tonal musics (i.e. popular music and classical music).

Chapter Five: Discussion

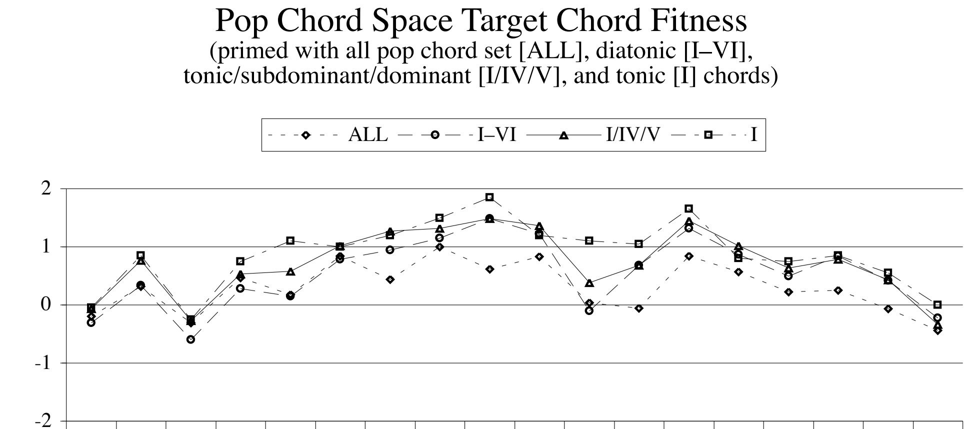
In this chapter, the concept of Pop Chord Space will be discussed and developed further.

5.1 Refining Pop Chord Space

The Pop Chord Space fitness ratings presented in the previous chapter resulted from tonic priming. In other words, the ratings conveyed Pop Chord Set fitness ratings in a condition where each chord had been preceded by the tonic chord only. Because 17 other primes were included in the experiment, I wanted to investigate whether different priming conditions would affect the perceived fitness of the target chords.

5.1.1 Priming Pop Chord Space

In the chart below (*Figure 13*), the target chord fitness ratings have been computed in various conditions on a target by target basis. First, the mean of all fitness ratings of a given target chord is computed ("ALL").[53] This is then repeated for all the other targets. Second, the mean of the fitness ratings of a given target chord – primed by any of the diatonic chords – is computed ("I–vi"). This is again repeated for all the other targets. Third, the mean of the fitness ratings of a given target chord – primed by the tonic, subdominant, and dominant chords – is computed ("I/IV/V"). This is again repeated for all the other targets. Finally, the mean of the fitness ratings of a given target chord – primed by the tonic (I) – is computed ("I"). This is again repeated for all the other targets.



	f	Ab	c	Eb	g	Bb	d	F	a	C	C7	e	G	G7	D7	A7	E7	B7
ALL	-0,20	0,32	-0,31	0,47	0,18	0,84	0,44	1,00	0,61	0,83	0,04	-0,06	0,84	0,57	0,23	0,25	-0,06	-0,44
I–VI	-0,31	0,33	-0,60	0,28	0,15	0,78	0,94	1,15	1,48	1,23	-0,10	0,68	1,32	0,87	0,49	0,84	0,43	-0,23
I/IV/V	-0,07	0,77	-0,27	0,53	0,58	1,02	1,27	1,32	1,48	1,37	0,38	0,68	1,45	1,02	0,63	0,78	0,43	-0,33
I	-0,05	0,85	-0,25	0,75	1,10	1,00	1,20	1,50	1,85	1,20	1,10	1,05	1,65	0,80	0,75	0,85	0,55	0,00

Figure 13. Pop Chord Space target chord fitness.

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[53] In this case, the target chords have been primed by all the Pop Chord Set chords.

The last, tonic priming condition, is actually the same set of values that was used in the previous chapter when Pop Chord Space was compared to Tonal Pitch Space. When we look closely at the chart presented above (*Figure 13*), it becomes evident that these ratings – primed by the tonic only – do not represent all the priming conditions, and neither do the ratings primed by all the Pop Chord Set chords. As a matter of fact, the latter condition seems to represent the ratings of all the other priming conditions the worst. In order to find out whether these conclusions are justified, a correlation matrix of the four priming conditions was created (*Table 13* below).

Table 13.
Correlation matrix of Pop Chord Space priming conditions.

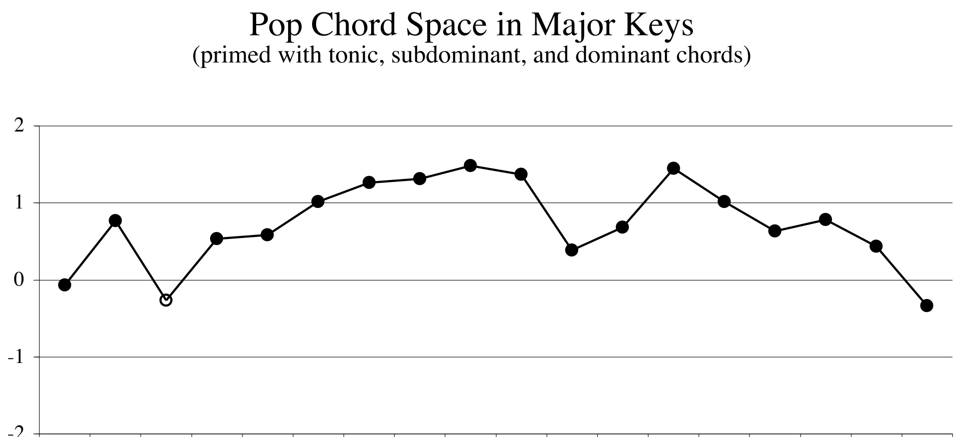
		All primes (ALL)	Diatonic primes (I–vi)	TSD primes (I/IV/V)	Tonic prime (I)
All primes (ALL)		1			
	N	-			
	P	-			
Diatonic primes (I–vi)		**,836**	1		
	N	18	-		
	P	,000	-		
TSD primes (I/IV/V)		**,907**	**,957**	1	
	N	18	18	-	
	P	,000	,000	-	
Tonic prime (I)		**,783**	**,856**	**,911**	1
	N	18	18	18	-
	P	,000	,000	,000	-

The between-condition correlations were all strong (r = .783 – .957) and significant (p = .000), as can be seen in *Table 13*. When compared to the other three conditions, "I/IV/V" priming had the highest correlation levels on average ($\overline{x_r}$ = .925), followed by "I–vi" ($\overline{x_r}$ = .883), "I" ($\overline{x_r}$ = .850), and finally "ALL" ($\overline{x_r}$ = .842), suggesting that priming by the tonic (I), subdominant (IV), and dominant (V) best represents the other priming conditions. This result is in line with Krumhansl and Kessler (1982): "In a major key the I, IV, and V chords are all major, and a progression involving these chords gives what may be the strongest possible instantiation of a major key". Thus, if we were looking for a robust and quantified harmonic hierarchy in major, counting on the fitness ratings provided by targets primed with "I/IV/V" would most likely be our best bet.

There is also one "hidden" result in *Table 13*. The four priming conditions presented here can be classified into two categories: the conditions with diatonic primes only ("I", "I/IV/V", and "I–vi"), and the condition including both diatonic and nondiatonic primes ("ALL"). It is safe to assume that these nondiatonic primes cause the "ALL" condition to receive the lowest correlation ratings when compared to the other, fully diatonic conditions, and, on the other hand, these nondiatonic primes are the least likely to establish a strong sense of key, so they (at least) have to be excluded from the priming set before making any conclusions about perceived harmonic hierarchy in major keys.

5.1.2 Presenting Pop Chord Space

As stated earlier, priming by the tonic (I), subdominant (IV), and dominant (V) was found to best represent all the other priming conditions – diatonic or nondiatonic. It can thus be reasoned that this priming condition should deliver the most reliable results of within-key harmonic hierarchy. For this very reason I am hereby proposing a profile of *harmonic hierarchy in popular music*, the Pop Chord Space, extracted from experimental target chord fitness ratings by priming the targets with the tonic, subdominant, and tonic chords (*Figure 14*). Note that the "C7" and "G7" chords have been added next to their corresponding triadic representations.



	f	Ab	c	Eb	g	Bb	d	F	a	C	C7	e	G	G7	D7	A7	E7	B7
PCS	-0,07	0,77	-0,27	0,53	0,58	1,02	1,27	1,32	1,48	1,37	0,38	0,68	1,45	1,02	0,63	0,78	0,43	-0,33

Figure 14. Pop Chord Space in major keys.

The first hypothesis of this study was "It is expected that the chords constituting the "road map of hit song harmony" (diatonic triads, secondary dominants, and modal interchange chords) [Pop Chord Set] are perceived as belonging to the default chord set in popular music". None of the target chords presented in *Figure 14* were perceived as "less (fitting) than neutral" (i.e. ≤ -.50), meaning that the hypothesis can be confirmed. It is also rather unlikely that chords *not* included here would receive ratings of ≥ -.50, and be considered as belonging to the Pop Chord Set. In hindsight, it would have been interesting, though, if chords further away from the tonic (such as the "bII" or "Db" – and the "vii" or "b" in **C** major) had been included in the experiment.

5.1.3 Discussing Pop Chord Space

At first look, the Pop Chord Space profile does not look too uniform. There seems to be three clearly visible points of deviation in the otherwise smooth profile, namely the chords "c", "C7", and "e". We will now examine these deviations one by one – starting from the left hand side of *Figure 14*.

"c"

In the stimuli used in the experiment, there was a moment without any harmonic content at the end of the context, right before the probe, consisting of a prime-target pair. This "moment of harmonic silence" may have been long enough (1739 ms) to lessen the effect of the context on key formation – even to the extent of rendering its effect neglible. Instead of relying on the key context presented to them, the subjects may have – at least in some cases – unconsciously rated the targets in relation to the primes only. This would explain why the "i" (or "c" in the key of **C**) was perceived as belonging to the Pop Chord Set, although, as stated before, it does not appear in actual works of popular music. In the end, the participants were only asked to rate the prevalence of the prime resolving into the target, and they were not explicitly required to do that in reference to a *major* key. This may have resulted in some ratings accidentally given in reference to a *minor* key – especially when the prime was a "i". For this reason, I would like to exclude the "i" chord from the Pop Chord Set altogether, and to make it visible, I have presented the chord with an open dot (o) in *Figure 14*.

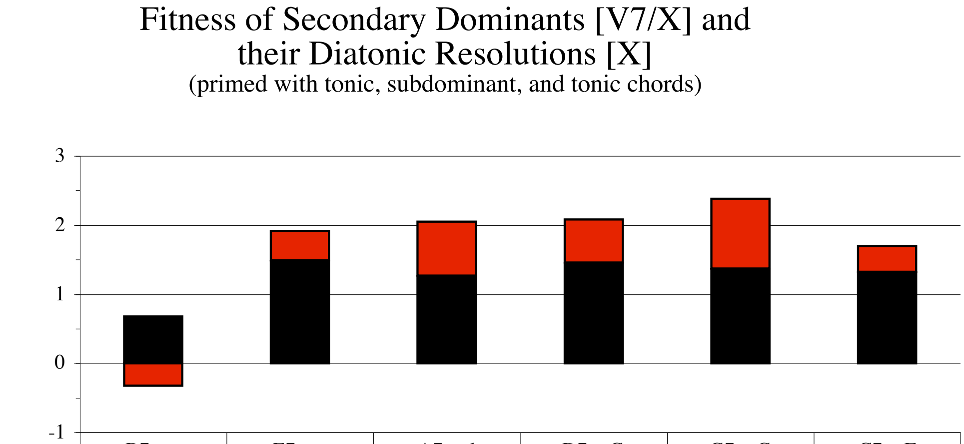
"C7"

The reason for the "V7/IV" (or "C7" in the key of **C**) residing so low in the hierachy is most likely due to the high directionality of the chord itself. When primed with the tonic chord only (see *Figure 13*), its rating is significatly higher, because "I > V7/IV" (or "C > C7" in the key of **C**) progressions are very common in tonal music. When, on the other, primed with the subdominant (IV) and the dominant (V) – as is the case with the Pop Chord Space profile presented in *Figure NN* – the fitness ratings go down, because "F > C7" and "G > C7" progressions are relatively rare. Note that the chords' directional tendencies can be verified from *Appendix E*.

"e"

As noted earlier, the "iii" chord (or "e" in the key of **C**) is generally considered as being relatively rare in harmonic progressions, and playing a weak role in defining the key (Piston, 1978; Krumhansl et al., 1982; Krumhansl, 1990). This can be seen quite clearly in the results of this study, too. But it is not only the "iii" that is harmonically weak. Its secondary dominant, the "V7/iii", is also rated low, being the lowest-rated dominant within the Pop Chord Set – just like the "iii" is the lowest-rated diatonic minor chord. This becomes evident when the fitness ratings of secondary dominants and their diatonic resolutions are combined (see *Figure 15* below).

In addition, the "iii" lacks a clear harmonic function that all the other diatonic chords (except the "vii°", of course) seem to possess: the tonics ("I" and "vi"), the subdominants ("ii" and "IV"), and the dominant ("V").



	B7 > e	E7 > a	A7 > d	D7 > G	G7 > C	C7 > F
V7/X	-0,33	0,43	0,78	0,63	1,02	0,38
X	0,68	1,48	1,27	1,45	1,37	1,32

Figure 15. Fitness of secondary dominants and their diatonic resolutions.

5.2 Pop Chord Space from a different perspective

Although the main focus of this study has been in figuring out the exact chord resolutions and the harmonic hierarchies found in popular music, this presentation would be partial without a brief overview of root motion.[54]

5.2.1 Pop Chord Space by root motion

Because the chord pairings used in the experiment were predetermined, it would have made no sense to calculate the *number* of certain intervals between the roots of adjacent chords. Instead, it was interesting to see whether different root motions would produce different fitness ratings. It is important to note up front that the fitness ratings will naturally have an effect on the root motion ratings, because fitness was the only parameter measured in the experiment.

First, the probes (all the 324 prime-target chord pairs) were manually labeled with a code, made up of two to three symbols. For example, "M3D" would refer to root motion of "major third down" (see *Table 14* for a key to the code). Note that since it is impossible to tell whether the roots of the chords are actually progressing upwards or downwards[55], the shortest path was always used as a reference for root motion labeling, essentially meaning that the largest root motion class was the tritone[56]. Next, the probes were sorted by root motion. Finally, sums and means of the (means of the) fitness ratings of a given root motion class were computed. The sums of means (*Figure 16*)

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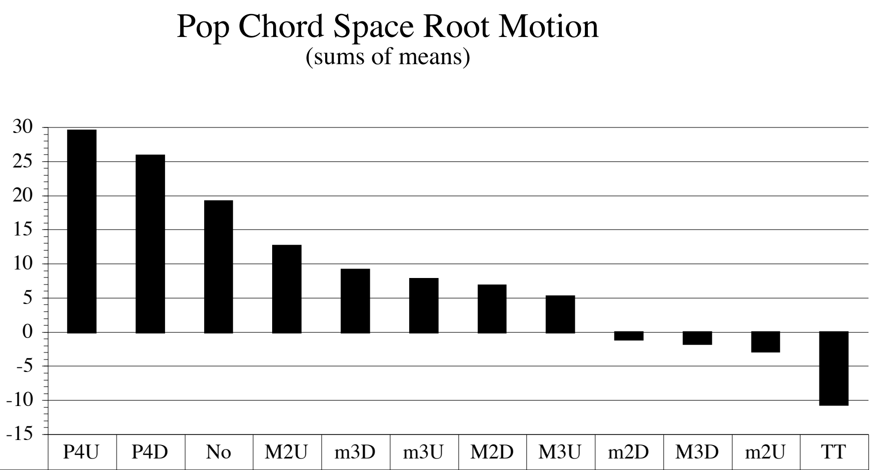
[54] Root motion refers to the directional distance (interval size and direction) between the roots of adjacent chords.
[55] At least in non-notated musics like popular music mostly is.
[56] The interval of augmented fourth or diminished fifth – the interval that splits the octave in two.

were calculated in case the means of means (*Figure 17*) values would not result in enough differentiation between the root motion classes. In the end, both of these approaches produced the same order of preference.

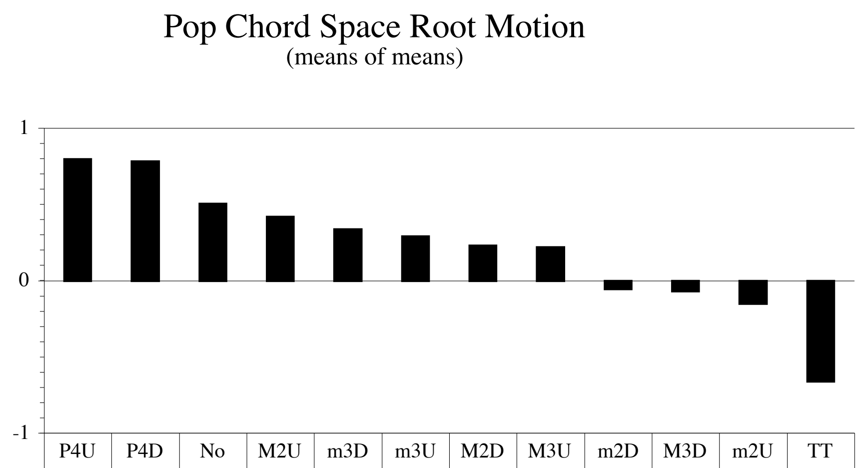
Table 14.
Key to root motion code.

P = perfect	2 = second	U = up
M = major	3 = third	D = down
m = minor	4 = fourth	No = no root motion
	TT = tritone	



	P4U	P4D	No	M2U	m3D	m3U	M2D	M3U	m2D	M3D	m2U	TT
Sums of Means	29,50	25,85	19,15	12,60	9,10	7,75	6,85	5,20	-1,05	-1,70	-2,85	-10,60

Figure 16. Pop Chord Space root motion (sums of means).



	P4U	P4D	No	M2U	m3D	m3U	M2D	M3U	m2D	M3D	m2U	TT
Means of Means	0,80	0,78	0,50	0,42	0,34	0,29	0,23	0,22	-0,06	-0,07	-0,15	-0,66

Figure 17. Pop Chord Space root motion (means of means).

For a cursory comparison with an existing set of results, a recent study was brought up. Anglade and Dixon (2008) studied chord sequences present in The Beatles' songs and in The Real Book[57] songs. They used inductive logic programming to extract harmony rules from manually labelled chords. The rules extracted included either root motion or chord quality information – or both. All the chord sequences were four measures in length.

Table 15.
Harmony rules of The Beatles and The Real Book (adapted from Anglade & Dixon, 2008). Arranged in order of coverage.

The Beatles		**The Real Book**	
Root motion	*Chord quality*	*Root motion*	*Chord quality*
P4U > P4D > P4U	M > M > M > M	P4U > P4U > P4U	m > D > m > D
No > No > No	M > M > M > m	P4U > P4U > No	m > D > M > m
P4U > M2U > P4U	m > M > M > M	m3D > P4U > P4U	D > m > D > m
M2U > P4U > P4U	M > m > M > M	P4U > P4D > P4U	m > m > m > m
-	M > M > m > M	P4U > P4U > m3D	D > D > D > D

As we can see in *Table 15*, the most popular root motions in the music of The Beatles are, in order of appearance: "P4U", "P4D", "No", and "M2U". These are the exact same directional distances (and in the exact same order) found in the chord progressions of the present study. The next highest rated root motion in Pop Chord Space was "m3D", which can conveniently be found in the third most popular progression in The Real Book. Thus, the outcome of this quick overview suggests that the root motion ratings of the Pop Chord Space most likely correlate with actual works of popular music[58]. Further analysis is beyond the scope of this study, but this topic would clearly benefit from further inspection.

5.2.2 Pop Chord Space by chord quality

For future reference, the breakdown of Pop Chord Space fitness ratings, categorized by chord quality, can be found in *Appendix F*.

[57] "The Real Book" can refer to any of the jazz "fake books" (collections of transcriptions of jazz compositions), although it usually refers to the infamous "illegal" Volume 1 of a series of fake books transcribed by students at Berklee College of Music in the 1970s.

[58] It should be noted here that the majority of the compositions (or "jazz standards") included in the (early) fake books represent the popular music (Broadway and Hollywood musical, and "Tin Pan Alley" songs) of the 1920s onwards – up until the birth of rock'n'roll.

Chapter Six: Conclusion

This study is my first attempt at describing harmonic hierarchy in popular music using the scientific method. Prior to this thesis, my knowledge of tonal harmony has mainly been based on self-made transcriptions and analyses, and textbooks written by others – not forgetting playing and writing music. The information provided by these sources has been highly subjective, often leaving me wondering whether it is at all true – as in "tried and true" or "ground truth". Now, after all the hard work with this study, I know that the answers to these ponderings can be provided by the scientific method, if anything. At the same time, I have come to realize that these answers do not come for free: it takes a lot of time and effort to first come up with the simplest hypothesis, and a lot more to prove it true – let alone publish the results. And if this was not enough, the scientific community is needed to corroborate the results by subsequent tests in order for the results to become reliable knowledge. To help them in their task, let us first look at the limitations of this study before proceeding to making recommendations for futher research and musical practice.

6.1 Limitations of this study

This study, while designed carefully, has its limitations. After the experiment had been carried out, I continued to read more and more literature about the topic, because, first of all, the majority of it was interesting, well written, and thoroughly reasoned. In addition, I seemed to learn new things every day, although it was rather frustrating at times, because some of the studies were in conflict with the experiment I had just finished. In the end, I think this is quite natural for a project like this. I have now come to learn that a master's thesis is more of a learning process than a life's work.

Pop Chord Set

The first limitation of this study has something to do with the number of chords included in the Pop Chord Set. I originally tried to include as few chords as possible, because the permutations of the chord pairings add up in powers of two ($18^2 = 324$, $19^2 = 361$, $20^2 = 400$ …). In other words, had I added the two chords mentioned earlier in the study ("bII" or "Db" and "vii" or "b"), for example, the participants of the experiment would have had to listen to 76 examples more. Anyway, it would have been interesting to include chords that were not supposed to belong to the Pop Chord Space in the first place, to give perspective. This brings us over to the next limitation.

Stimuli

The stimuli used in the experiment were probably too long. Had they been shorter, it would have been possible to make the listening experience shorter for the subjects, or to add more stimuli to the experiment. On the other hand, the context and the target under study may have been to far apart from each other (approximately seven seconds) for the context to really have an effect on the target. After all, our immediate memory of the previous schema event starts to fade rapidly after six to eight seconds (Gjerdingen, 1986). Anyway, the probe was constructed so that it had its own "close context" in the prime chord presented, so this was probably not as fatal a mistake as it may seem. It should also be remembered that the local role of the cadence (or chord resolution) prevails over its function in the global structure (Bigand & Parncutt, 1999), so the importance of the context in the perception of tonal forms like this is smaller than that of the cadence anyway.

In addition, the stimuli were skewed, because there was no key context presented after the probe. Had there been one, I believe that its inclusion might have had an effect on the subjects' prevalence ratings, but if this work had been a strict study of harmonic hierarchies from the get-go, the concept of symmetrical context may have been appropriate.

The instrumentation used in the stimuli may have had a minor effect on the results. I wanted to use complex tones instead of Shepard tones, for example, but the tone of the particular acoustic steel-string guitar used to record the audio excerpts was almost *too* complex: the instrument clearly had very loud overtones (or harmonics). In addition, the tuning of the guitar – although equal-tempered at heart – usually has its share of quirks and inconsistencies, such as out-of-tune (usually sharp) notes at the first couple of frets, making differently fretted chords unequal in intonation.

Methodology

In hindsight, the questions asked from the subjects were somewhat vague. I may have tried too much by basically asking the participants to try to be both subjective and objective at the same time. The next time around, I know that if I am looking for the level of prevalence (i.e. how common or probable a certain chord resolution objectively is), I might as well measure the phenomenon myself by extracting the features from existing music. On the other hand, if I am looking for the rating of fitness (i.e. information on how subjectively well a chord fits a given context), I might as well ask it from the subjects. By acting so, the level of speculation on the results of the study would most likely end up being much lower. Nevertheless, had I been completely subjective or objective in this study, I may not have found the interesting parallels between the Pop Chord Space and the Tonal Pitch Space, for example.

In addition, there were a few other methodological limitations found during the research process: for example, the reaction times or processing speed of the subjects were not measured (which would have made this a priming study), the rating scale used in the experiment coud have been finer (like the seven-point scale used by Krumhansl), the subjects were not asked if they possessed normal hearing abilities, and… – the list goes on.

Despite these limitations, I am very happy about the way the results turned out, because I can see myself using them in practice when teaching or writing music. Although the results may not represent the ground truth in popular music harmony, they are good enough (for now) to give direction to my future endeavours, be they scientific or practical – or both. At the same time, I am also happy with the sheer amount of information I managed to gather and (partly) internalize during the research process.

6.2 Recommendations for further research

The issue of root motion was briefly discussed at the end of the previous chapter. It, like the following topics, would benefit from further research.

Metric issues

The effect of harmonic rhythm on the perception of chord fitness was not studied here. Aspects of harmonic rhythm (Boltz, 1989), structural accents (Dawe et al., 1995), and "the general temporalities of music" (Kramer, 1988) have been studied before, but the field of study is still at an early stage. Based on the results of this study, the metric position of a chord within the progression seems to affect its perception (see *Appendix E: Chord directionality*). In addition, most of the studies so far have concentrated on quadruple meter (i.e. 4/4 time) – maybe it is finally time (pun intended) for studies in triple (i.e. 3/4, 6/8) and compound (i.e. 5/4, 7/4) meter.

Harmonic issues

It is quite obvious that minor keys would need the same attention as major keys. I have yet to see a study investigating harmony in combined (or compound) minor, although in musical practice – at least in popular music and even jazz – chord degrees of parallel minor keys have always been mixed and matched.[59] Instead, minor keys are often studied in a way that considers the different minors (natural and harmonic, for example) as almost separate harmonic entities even though they are usually not – not even in classical music.

I am sure that instable harmonic areas (or modulations) would prove an interesting topic to study. The *a priori* and *a posteriori* harmonic functions of a chord degree associated with a modulation are

[59] For example, the dorian minor "IV7" in *Oye Como Va* by Tito Puente (and Carlos Santana), the dorian (or [real] melodic/"jazz") minor "vi-7b5" in *Angel Eyes* (and numerous other jazz standards), the natural minor "v-7" in minor blues, or the natural minor "bVI > bVII" in the majority of the songs by Iron Maiden.

not that well known. Most of the past studies on harmonic hierarchies have focused on stable key areas, so maybe it is time to expand and elaborate on the findings of Toiviainen and Krumhansl (2003), who used a concurrent probe-tone method[60] to show that the process of tonality induction is indeed dynamic in nature. In general, these cross-domain studies – be it *music psychology and computational modeling* or *music and linguistics* – bring welcome perspective to other studies with a more limited focus.

Furthermore, full-context studies on musical expectancies (such as Schmuckler, 1989) would bring important information about the interdependence or independence of melody and harmony in music perception. Exploring this relationship between contrasting musical styles – such as contrapunctally written classical music and chordally written popular music – would most likely provide an interesting angle to the study. In addition, parallel approaches to the subject would be the study of the effect of voice-leading to the perception of harmony, and the study of the extent of independence of tonal and harmonic hierachies. The latter approach could be studied by investigating whether the ratings of a specific chord could be predicted by the ratings given to the chord's component pitch classes (such as the key profiles of Krumhansl and Shepard, 1989; Krumhansl and Kessler, 1982). In fact, this method could be applied to the experimental data gathered during this study, too.

Finally, the vast majority of the previous studies on harmonic hierarchies has focused on triads or (diatonic) dominant sevenths only. The effect of chord extensions on harmonic perception has not been studied to my knowledge, although they have a very central role in certain musical styles, such as jazz. Maybe a music-theoretical model could first be compiled or created, and then compared to the results of a music-psychological experiment.

In addition to the recommendations presented in detail above, I feel that some demographic issues (e.g. experts vs. non-experts, different cultural backgrounds) should continue to be addressed in future studies. Also, commercial approaches to music perception and production would be more than welcome. Who knows, somebody might even devise an algorithm called "The Virtual Songwriter" based on the results of this current and other related studies – at least the domain "www.virtualsongwriter.com" is already taken!

[60] The probe-tone sounding *continuously* with the music, as opposed to "probing" *after* the context.

6.3 Recommendations for musical practice

The fundamental research problem of the current study was a practical one, and I thought it might be appropriate to end this presentation with a practical solution.

Pop Chord Space as a songwriting tool

While looking at the charts provided in *Appendix E*, I asked myself a question: "If I was the harmonically handicapped novice songwriter described in the introduction, would I be able to write common chord progressions in the style of popular music with the help of these charts?". The answer was a simple "No!". After reaching this self-evident conclusion, I started to look for ways to distill the information provided by the charts in *Appendix E* into simple and practically oriented visualizations. While looking for a solution, I bumped into the metaphorical representation of musical intervals by Hindemith (1942):

> "If we think of the series of tones grouped around the parent tone C as a planetary system, then C is the sun, surrounded by its descendant tones as the sun is surrounded by its planets. … As the distance increases, the warmth, light, and power of the sun diminish, and the tones lose their closeness of relationship. The intervals correspond to the distances of the various planets from the sun."

Here I got the idea of target chords (planets) revolving around a prime chord (the sun), with the relative size of a given "planet" representing the prevalence of resolution into that direction. In order to make the tool as simple and practical as possible, I modified the original data in three respects: first, only resolutions with an indisputably positive rating (i.e. > .50; closer to "+1" than "0") were included; second, the progressions including the "i" (or "c" in the key of **C**) were excluded (see previous chapter for an explanation), and third, repetitions of chords were omitted, because they are not, according to Schmuckler (1989) progressions, per se.

The resolutions were organized in three categories by target rating: "maybe" (.51–1.00), "yes" (1.01–1.50), and "definitely" (1.51–2.00). The visualized results of this approach can be seen in *Appendix G*, where the prevalence of a given resolution is first indicated by the *size* of the target chord "planet" in the key of **C** major, followed by a modified version, where the prevalence of the given resolution is indicated by the *darkness*[61] of the target, and the chords themselves are represented as relative degrees in order to facilitate the transposition of the model to different major keys. With the help of this simple "songwriting tool", the novice songwriter can now easily explore the common harmonic options available in popular music.

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[61] Key: "definitely" = white, "yes" = light gray, "maybe" = dark gray.

6.4 Summary

All in all, I have learned many things during this process. I have learned that tonal harmony is not one universal set of rules (although they may tell you otherwise, ahem...), but there are most likely many style-dependent variations of it – variations in desperate need of further study. In addition, tonal harmony does not seem to be a static entity, but a process: "the dissonance of the previous season becomes the consonance of the next". A great deal of progress has thankfully been made since the days of Vincent d'Indy:

> “Musically, chords do not exist, and harmony is not the science of chords. The study of chords per se is, from a musical point of view, completely in error esthetically, for harmony comes from melody and ought never to be separated from it in practice.” (d'Indy, 1912; translated by Gjerdingen, 1995)

This comment comes from a very narrow perspective – even by 1912 standards – as it tries to convince the reader that there is only one right way of composing or analyzing music. The statement above may be at least partly true in some forms of melody-induced contrapunctal writing of Western art music, but it does not apply to any harmony-induced approaches to composition or songwriting. Ironically, the existence of chordal writing was recognized by Paul Hindemith (1942) in as early as 1937, but some music professionals still have a hard time believing it. Whatever the verdict, I strongly believe that harmony can also be studied separately from melody. After all, there are musical styles where harmonic progressions are not a by-product, but the foundation on top of which melodies are built. Practical examples of harmony-induced thinking can be found in both jazz (the bebop player improvising on "the changes" – the chords of a familiar song) and popular music (the songwriter strumming chords on the acoustic guitar and humming away – with a new melody in mind).

To summarize, I believe that models of tonal-harmonic hierarchies should be neither universal nor static. It was Temperley (1999), who suggested that the Krumhansl and Schmuckler (in Krumhansl, 1990) key-finding algorithm should be modified so that the weight of the seventh scale degree would increase. I hope that he made this suggestion in order for the model to better account for the prevalence of seventh chords in music – or even certain styles of music. On my behalf, I have tried to make my contribution by investigating style-specific harmonic features, and I am willing to try to keep the study moving forward – following the musical practice, wherever it may take. Until then!

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Appendix A: Tonal Harmony

In the following tables, the X axis represents the horizontal aspect of tonality, whereas the Y axis represents the vertical aspect (i.e. scales and chords, respectively).

Table 16.
The chromatic scale (12 pitch classes starting from the note c).

c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'	a#'/bb'	b'	c''
b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'	a#'/bb'	b'
a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'	a#'/bb'
a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'
g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'
g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'
f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'
f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'
e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'
d#/eb	e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'
d	d#/eb	e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'
c#/db	d	d#/eb	e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'
c	**c#/db**	**d**	**d#/eb**	**e**	**f**	**f#/gb**	**g**	**g#/ab**	**a**	**a#/bb**	**b**	**c'**

Table 17.
*Pitches of a diatonic scale (**C** major).*

c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'	a#'/bb'	b'	c''
b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'	a#'/bb'	b'
a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'	a#'/bb'
a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'
g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'
g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'
f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'
f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'
e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'
d#/eb	e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'
d	d#/eb	e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'
c#/db	d	d#/eb	e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'
c	c#/db	**d**	d#/eb	**e**	**f**	f#/gb	**g**	g#/ab	**a**	a#/bb	**b**	**c'**

Table 18.
*Pitches of diatonic seventh chords (**C** major).*

c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'	a#'/bb'	b'	c''
b	c'	c#'/db'	d'	d#'/eb'	**e'**	f'	f#'/gb'	g'	g#'/ab'	a'	a#'/bb'	**b'**
a#/bb	b	**c'**	c#'/db'	**d'**	d#'/eb'	e'	**f'**	f#'/gb'	**g'**	g#'/ab'	**a'**	a#'/bb'
a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'	a'
g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'	f#'/gb'	g'	g#'/ab'
g	g#/ab	**a**	a#/bb	**b**	**c'**	c#'/db'	**d'**	d#'/eb'	**e'**	f'	f#'/gb'	**g'**
f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	**f'**	f#'/gb'
f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'	d#'/eb'	e'	f'
e	f	f#/gb	g	g#/ab	**a**	a#/bb	**b**	c'	c#'/db'	d'	d#'/eb'	**e'**
d#/eb	e	**f**	f#/gb	**g**	g#/ab	a	a#/bb	b	**c'**	c#'/db'	**d'**	d#'/eb'
d	d#/eb	e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'	d'
c#/db	d	d#/eb	e	f	f#/gb	g	g#/ab	a	a#/bb	b	c'	c#'/db'
c	c#/db	**d**	d#/eb	**e**	**f**	f#/gb	**g**	g#/ab	**a**	a#/bb	**b**	**c'**

Appendix B: Patents on Automatic Accompaniment

AOKI, E. (1998). *Chord detection method and apparatus for detecting a chord progression of an input melody*. United States Patent #5,760,325.

BAGGI, D. L. (1984). *Harmony machine*. United States Patent #4,468,998.

BEZEAU, JR., R. A. (1991). *Chord progression finder*. United States Patent #5,029,507.

FAY, C. T. (1998). *System and process for composing musical sections*. United States Patent #5,753,843.

GUNN, D. (1990). *Chord key calculator assembly*. United States Patent #4,961,362.

HAYAKAWA, T., & ISHIBASHI, M. (1999). *Automatic accompaniment apparatus and method with chord variety progression patterns, and machine readable medium containing program therefore (sic.)*. United States Patent #5,942,710.

HAYASHI, T., & MATSUBARA, K. (1996). *Apparatus for harmonizing melody using results of melody analysis*. United States Patent #5,510,572.

IKEDA, T., & SUZUKI, S. (1995). *Automatic accompaniment instrument for automatically performing an accompaniment that is based on a chord progression formed by a sequence of chords*. United States Patent #5,418,316.

INO, M. (1991). *Apparatus for producing a chord progression by connecting chord patterns*. United States Patent #5,052, 267.

KITAMURA, M. (1996). *Automatic performance apparatus for storing chord progression suitable that is user settable for adequately matching a performance style (sic.)*. United States Patent #5,481,066.

KOZUKI, K. (1992). *Automatic key designating apparatus*. United States Patent #5,153,361.

KURAKAKE, Y. (1998). *Automatic performance apparatus*. United States Patent #5,723,803.

LEONARD, V. M. (1977). *Chord progression selector*. Unites States Patent #4,002,097.

MINAMITAKA, J. (1991). *Automatic accompaniment apparatus*. United States Patent #5,003,860.

MINAMITAKA, J. (1993). *Technique for selecting a chord progression for a melody*. United States Patent #5,218,153.

OKUDA, H., & MINAMITAKA, J. (1993). *Apparatus for determining tonality for chord progression*. United States Patent #5,179,241.

OKUDA, H., YOSHIMURA, H., & NAKAMURA, C. (1994). *Music apparatus for determining tonality from chord progression for improved accompaniment*. United States Patent #5,302,777.

SEKIZUKA, M. (1992). *Auto-accompaniment apparatus with auto-chord progression of accompaniment tones (sic.)*. United States Patent #5,085,118.

TAKANO, J. (1998). *Chord progression input/modification device*. United States Patent #5,852,252.

Appendix C: Experiment Questionnaire

Table 19.
Form used to collect background information from the participants during the experiment. First in Finnish (above), then translated into English (below).

Harmoniset odotukset popmusiikissa | Kyselylomake musiikinopiskelijoille

1. Taustatiedot

Muodollinen musiikkikoulutus (vuotta)

1–5	6–10	11–15	16–20	21–99
○	○	○	○	○

Pääinstrumentti

melodiasoitin	harmoniasoitin	rytmisoitin	en soita enkä laula
○	○	○	○

Kuuntelutottumukset: Kuuntelen popmusiikkia...

en koskaan	harvoin	satunnaisesti	viikoittain	päivittäin
○	○	○	○	○

Oma (pääasiallinen) musiikkityyli

World	Blues	Klassinen	Country/Bluegrass	Dance
○	○	○	○	○
Folk/Traditional	Electronic	Heavy/Metal	Hip-hop/Rap	Jazz
○	○	○	○	○
Latin	Pop	R&B/Soul/Funk	Reggae	Rock
○	○	○	○	○

○ ei mikään (tai osa/kaikki) edellisistä, "All-around"

Harmonic Expectations in Popular Music | Questionnaire for Music Students

1. Background Information

Formal music education (years)

1–5	6–10	11–15	16–20	21–99
○	○	○	○	○

Main instrument

Melody	Harmony	Rhythm	I don't play or sing
○	○	○	○

Listening habits: "I listen to popular music..."

never	rarely	casually	weekly	daily
○	○	○	○	○

My own (primary) musical style

World	Blues	Classical	Country/Bluegrass	Dance
○	○	○	○	○
Folk/Traditional	Electronic	Heavy/Metal	Hip-hop/Rap	Jazz
○	○	○	○	○
Latin	Pop	R&B/Soul/Funk	Reggae	Rock
○	○	○	○	○

○ none (or some/all) of the above, "All-around"

Table 20.
Beginning of a (long!) form used to collect data about the participants' harmonic expectations during the experiment. First in Finnish (above), then translated into English (below).

2. Kuunteluesimerkit (EOS = "En osaa sanoa")

Esimerkki 1

hyvin harvinainen	melko harvinainen	neutraali (EOS)	melko tavallinen	hyvin tavallinen
○	○	○	○	○

Esimerkki 2

hyvin harvinainen	melko harvinainen	neutraali (EOS)	melko tavallinen	hyvin tavallinen
○	○	○	○	○

Esimerkki 3

hyvin harvinainen	melko harvinainen	neutraali (EOS)	melko tavallinen	hyvin tavallinen
○	○	○	○	○

Esimerkki 4

hyvin harvinainen	melko harvinainen	neutraali (EOS)	melko tavallinen	hyvin tavallinen
○	○	○	○	○

Esimerkki 5

hyvin harvinainen	melko harvinainen	neutraali (EOS)	melko tavallinen	hyvin tavallinen
○	○	○	○	○

2. Listening Examples (IDK = "I Don't Know")

Example 1

very rare	somewhat rare	neutral (IDK)	somewhat common	very common
○	○	○	○	○

Example 2

very rare	somewhat rare	neutral (IDK)	somewhat common	very common
○	○	○	○	○

Example 3

very rare	somewhat rare	neutral (IDK)	somewhat common	very common
○	○	○	○	○

Example 4

very rare	somewhat rare	neutral (IDK)	somewhat common	very common
○	○	○	○	○

Example 5

very rare	somewhat rare	neutral (IDK)	somewhat common	very common
○	○	○	○	○

Example 6

very rare	somewhat rare	neutral (IDK)	somewhat common	very common
○	○	○	○	○

Appendix D: Cross-Subject Correlation Matrix

Table 21.
Cross-subject correlations for ratings of prevalence.

	pp001	pp002	pp003	pp004	pp005	pp006	pp007	pp008	pp009	pp010	pp011	pp012	pp013	pp014	pp016	pp017	pp018	pp019	pp020	pp021
pp001	1																			
N	-																			
P	-																			
pp002	**,413**	1																		
N	324	-																		
P	,00	-																		
pp003	**,392**	**,490**	1																	
N	324	324	-																	
P	,00	,00	-																	
pp004	**,414**	**,488**	**,446**	1																
N	324	324	324	-																
P	,00	,00	,00	-																
pp005	**,402**	**,387**	**,404**	**,334**	1															
N	324	324	324	324	-															
P	,00	,00	,00	,00	-															
pp006	**,535**	**,489**	**,490**	**,544**	**,331**	1														
N	324	324	324	324	324	-														
P	,00	,00	,00	,00	,00	-														
pp007	**,443**	**,508**	**,436**	**,505**	**,370**	**,467**	1													
N	324	324	324	324	324	324	-													
P	,00	,00	,00	,00	,00	,00	-													
pp008	**,412**	**,582**	**,529**	**,539**	**,436**	**,496**	**,547**	1												
N	324	324	324	324	324	324	324	-												
P	,00	,00	,00	,00	,00	,00	,00	-												
pp009	**,406**	**,485**	**,410**	**,544**	**,329**	**,493**	**,408**	**,519**	1											
N	324	324	324	324	324	324	324	324	-											
P	,00	,00	,00	,00	,00	,00	,00	,00	-											
pp010	**,329**	**,472**	**,408**	**,379**	**,328**	**,350**	**,382**	**,566**	**,387**	1										
N	324	324	324	324	324	324	324	324	324	-										
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	-										
pp011	**,295**	**,472**	**,334**	**,242**	**,310**	**,335**	**,293**	**,307**	**,120**	**,341**	1									
N	324	324	324	324	324	324	324	324	324	324	-									
P	,00	,00	,00	,00	,00	,00	,00	,00	,03	,00	-									
pp012	**,344**	**,431**	**,427**	**,337**	**,336**	**,403**	**,525**	**,434**	**,339**	**,470**	**,298**	1								
N	324	324	324	324	324	324	324	324	324	324	324	-								
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-								
pp013	**,256**	**,399**	**,292**	**,213**	**,275**	**,229**	**,351**	**,406**	**,171**	**,482**	**,461**	**,372**	1							
N	324	324	324	324	324	324	324	324	324	324	324	324	-							
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-							
pp014	**,394**	**,429**	**,386**	**,403**	**,316**	**,428**	**,392**	**,409**	**,489**	**,346**	**,281**	**,377**	**,272**	1						
N	324	324	324	324	324	324	324	324	324	324	324	324	324	-						
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-						
pp016	**,341**	**,472**	**,428**	**,435**	**,391**	**,462**	**,374**	**,488**	**,361**	**,487**	**,328**	**,409**	**,320**	**,344**	1					
N	324	324	324	324	324	324	324	324	324	324	324	324	324	324	-					
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-					
pp017	**,360**	**,470**	**,315**	**,296**	**,302**	**,389**	**,376**	**,379**	**,365**	**,372**	**,360**	**,342**	**,360**	**,340**	**,257**	1				
N	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	-				
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-				
pp018	**,412**	**,522**	**,503**	**,439**	**,442**	**,527**	**,499**	**,576**	**,536**	**,443**	**,389**	**,444**	**,369**	**,439**	**,493**	**,421**	1			
N	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	-			
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-			
pp019	**,405**	**,402**	**,406**	**,363**	**,280**	**,432**	**,395**	**,400**	**,494**	**,333**	**,247**	**,361**	**,282**	**,390**	**,375**	**,231**	**,504**	1		
N	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	-		
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-		
pp020	**,298**	**,368**	**,296**	**,271**	**,212**	**,262**	**,354**	**,418**	**,284**	**,416**	**,291**	**,249**	**,381**	**,286**	**,288**	**,213**	**,370**	**,312**	1	
N	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	-	
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-	
pp021	**,379**	**,548**	**,469**	**,405**	**,376**	**,545**	**,405**	**,567**	**,446**	**,529**	**,453**	**,368**	**,507**	**,369**	**,473**	**,440**	**,618**	**,404**	**,498**	1
N	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	324	-
P	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	-

Note. The single outlying participant (pp0015) is not shown. Small correlations (.1–.3) are shown against white, medium correlations (.3–.5) against light gray, and large correlations (.5–1.0) against medium gray backgrounds.

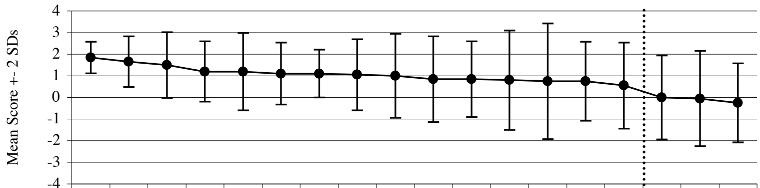
Appendix E: Chord Fitness and Directionality

1. Diatonic triads

a) C major triad ("C")

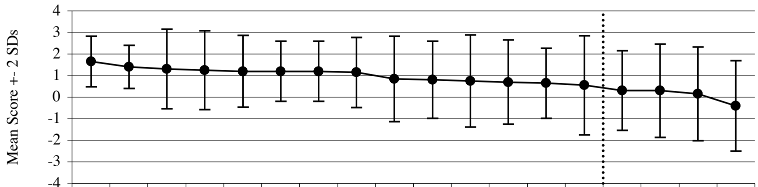
Figure 18. From top to bottom: *"C" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "C" chord as a prime and a target*, and *"C" chord directionality*, showing the difference of fitness between prime and target conditions.

C > X



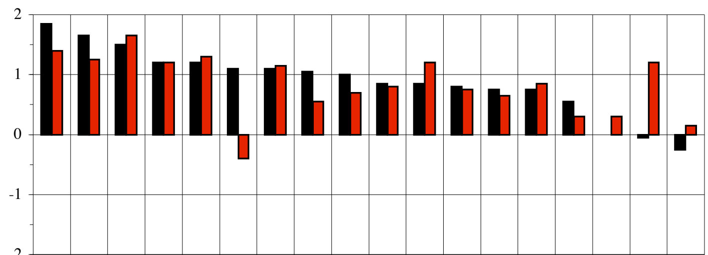
	a	G	F	C	d	C7	g	e	Bb	A7	Ab	G7	D7	Eb	E7	B7	f	c
Series1	1,85	1,65	1,50	1,20	1,20	1,10	1,10	1,05	1,00	0,85	0,85	0,80	0,75	0,75	0,55	0,00	-0,05	-0,25

X > C



	F	a	d	G	Ab	C	f	g	Eb	A7	G7	Bb	D7	e	B7	E7	c	C7
Series1	1,65	1,40	1,30	1,25	1,20	1,20	1,20	1,15	0,85	0,80	0,75	0,70	0,65	0,55	0,30	0,30	0,15	-0,40

Fitness of “C” Chord as a Prime [C > X] and a Target [X > C]



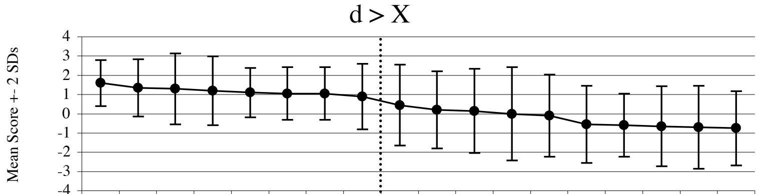
	a	G	F	C	d	C7	g	e	Bb	A7	Ab	G7	D7	Eb	E7	B7	f	c
■C > X	1,85	1,65	1,50	1,20	1,20	1,10	1,10	1,05	1,00	0,85	0,85	0,80	0,75	0,75	0,55	0,00	-0,05	-0,25
■X > C	1,40	1,25	1,65	1,20	1,30	-0,40	1,15	0,55	0,70	0,80	1,20	0,75	0,65	0,85	0,30	0,30	1,20	0,15

“C” Chord Directionality
(difference of fitness between prime [C > X] and target [X > C] conditions)

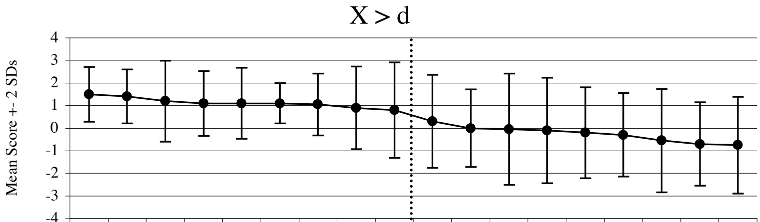
	C7	f	e	a	G	c	Ab	Bb	B7	E7	F	d	D7	Eb	G7	A7	g	C
DIFF	1,50	1,25	0,50	0,45	0,40	0,40	0,35	0,30	0,30	0,25	0,15	0,10	0,10	0,10	0,05	0,05	0,05	0,00
C > X	1,10	-0,05	1,05	1,85	1,65	-0,25	0,85	1,00	0,00	0,55	1,50	1,20	0,75	0,75	0,80	0,85	1,10	1,20
X > C	-0,40	1,20	0,55	1,40	1,25	0,15	1,20	0,70	0,30	0,30	1,65	1,30	0,65	0,85	0,75	0,80	1,15	1,20

b) D minor triad ("d")

Figure 19. From top to bottom: *"d" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "d" chord as a prime and a target*, and *"d" chord directionality*, showing the difference of fitness between prime and target conditions.

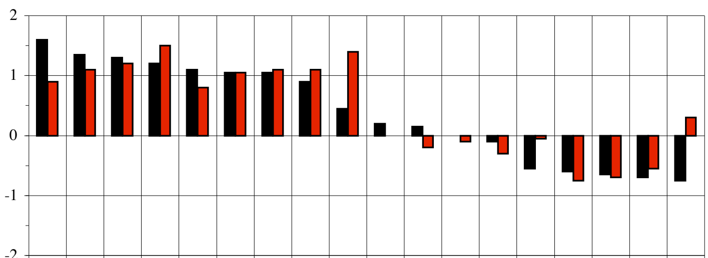


	a	G	C	F	Bb	d	G7	A7	g	Eb	D7	e	E7	f	Ab	B7	c	C7
Series1	1,60	1,35	1,30	1,20	1,10	1,05	1,05	0,90	0,45	0,20	0,15	0,00	-0,10	-0,55	-0,60	-0,65	-0,70	-0,75



	F	g	C	A7	G7	G	d	a	Bb	C7	Eb	f	e	D7	E7	c	B7	Ab
Series1	1,50	1,40	1,20	1,10	1,10	1,10	1,05	0,90	0,80	0,30	0,00	-0,05	-0,10	-0,20	-0,30	-0,55	-0,70	-0,75

Fitness of “d” Chord as a Prime [d > X] and a Target [X > d]



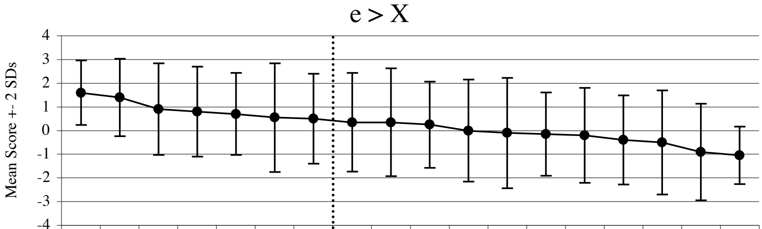
	a	G	C	F	Bb	d	G7	A7	g	Eb	D7	e	E7	f	Ab	B7	c	C7
d > X	1,60	1,35	1,30	1,20	1,10	1,05	1,05	0,90	0,45	0,20	0,15	0,00	-0,10	-0,55	-0,60	-0,65	-0,70	-0,75
X > d	0,90	1,10	1,20	1,50	0,80	1,05	1,10	1,10	1,40	0,00	-0,20	-0,10	-0,30	-0,05	-0,75	-0,70	-0,55	0,30

“d” Chord Directionality
(difference of fitness between prime [d > X] and target [X > d] conditions)

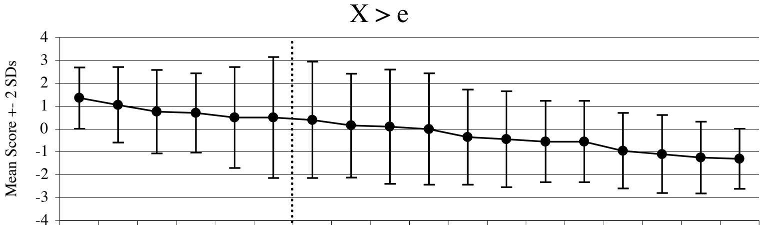
	C7	g	a	f	D7	F	Bb	G	A7	Eb	E7	Ab	c	C	e	G7	B7	d
DIFF	1,05	0,95	0,70	0,50	0,35	0,30	0,30	0,25	0,20	0,20	0,20	0,15	0,15	0,10	0,10	0,05	0,05	0,00
d > X	-0,75	0,45	1,60	-0,55	0,15	1,20	1,10	1,35	0,90	0,20	-0,10	-0,60	-0,70	1,30	0,00	1,05	-0,65	1,05
X > d	0,30	1,40	0,90	-0,05	-0,20	1,50	0,80	1,10	1,10	0,00	-0,30	-0,75	-0,55	1,20	-0,10	1,10	-0,70	1,05

c) E minor triad ("e")

Figure 20. From top to bottom: "*e*" *chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of* "*e*" *chord as a prime and a target*, and "*e*" *chord directionality*, showing the difference of fitness between prime and target conditions.

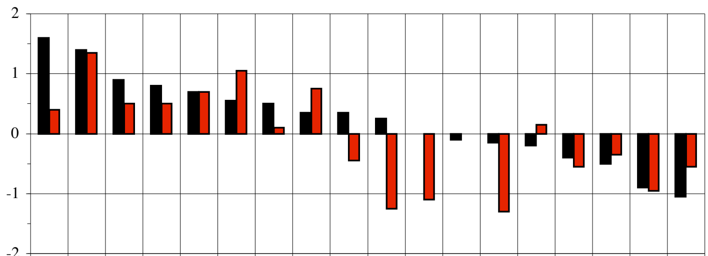


	A7	a	G	F	e	C	G7	B7	E7	Eb	Bb	d	Ab	D7	g	C7	f	c
Series1	1,60	1,40	0,90	0,80	0,70	0,55	0,50	0,35	0,35	0,25	0,00	-0,10	-0,15	-0,20	-0,40	-0,50	-0,90	-1,05



	a	C	B7	e	F	G	A7	D7	G7	d	C7	E7	c	g	f	Bb	Eb	Ab
Series1	1,35	1,05	0,75	0,70	0,50	0,50	0,40	0,15	0,10	0,00	-0,35	-0,45	-0,55	-0,55	-0,95	-1,10	-1,25	-1,30

Fitness of "e" Chord as a Prime [e > X] and a Target [X > e]



	A7	a	G	F	e	C	G7	B7	E7	Eb	Bb	d	Ab	D7	g	C7	f	c
e > X	1,60	1,40	0,90	0,80	0,70	0,55	0,50	0,35	0,35	0,25	0,00	-0,10	-0,15	-0,20	-0,40	-0,50	-0,90	-1,05
X > e	0,40	1,35	0,50	0,50	0,70	1,05	0,10	0,75	-0,45	-1,25	-1,10	0,00	-1,30	0,15	-0,55	-0,35	-0,95	-0,55

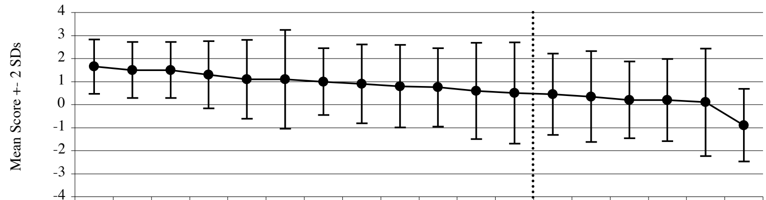
"e" Chord Directionality
(difference of fitness between prime [e > X] and target [X > e] conditions)

	Eb	A7	Ab	Bb	E7	C	c	G	G7	B7	D7	F	g	C7	d	f	a	e
DIFF	1,50	1,20	1,15	1,10	0,80	0,50	0,50	0,40	0,40	0,40	0,35	0,30	0,15	0,15	0,10	0,05	0,05	0,00
e > X	0,25	1,60	-0,15	0,00	0,35	0,55	-1,05	0,90	0,50	0,35	-0,20	0,80	-0,40	-0,50	-0,10	-0,90	1,40	0,70
X > e	-1,25	0,40	-1,30	-1,10	-0,45	1,05	-0,55	0,50	0,10	0,75	0,15	0,50	-0,55	-0,35	0,00	-0,95	1,35	0,70

d) F major triad ("F")

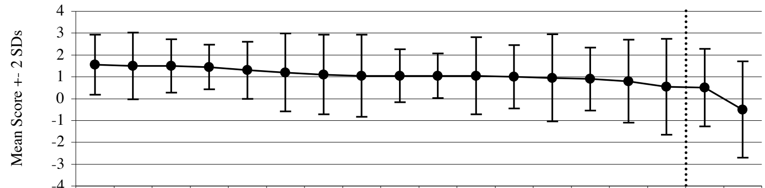
Figure 21. From top to bottom: "*F*" *chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "F" chord as a prime and a target*, and *"F" chord directionality*, showing the difference of fitness between prime and target conditions.

F > X



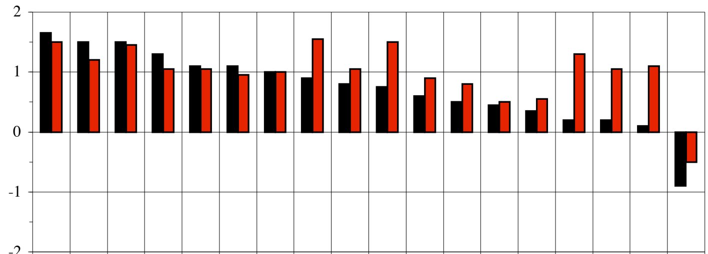
	C	d	G	G7	Ab	a	F	Bb	D7	Eb	g	e	A7	f	C7	E7	c	B7
Series1	1,65	1,50	1,50	1,30	1,10	1,10	1,00	0,90	0,80	0,75	0,60	0,50	0,45	0,35	0,20	0,20	0,10	-0,90

X > F



	Bb	C	Eb	G	C7	d	c	Ab	D7	E7	G7	F	a	g	e	f	A7	B7
Series1	1,55	1,50	1,50	1,45	1,30	1,20	1,10	1,05	1,05	1,05	1,05	1,00	0,95	0,90	0,80	0,55	0,50	-0,50

Fitness of “F” Chord as a Prime [F > X] and a Target [X > F]



	C	d	G	G7	Ab	a	F	Bb	D7	Eb	g	e	A7	f	C7	E7	c	B7
F > X	1,65	1,50	1,50	1,30	1,10	1,10	1,00	0,90	0,80	0,75	0,60	0,50	0,45	0,35	0,20	0,20	0,10	-0,90
X > F	1,50	1,20	1,45	1,05	1,05	0,95	1,00	1,55	1,05	1,50	0,90	0,80	0,50	0,55	1,30	1,05	1,10	-0,50

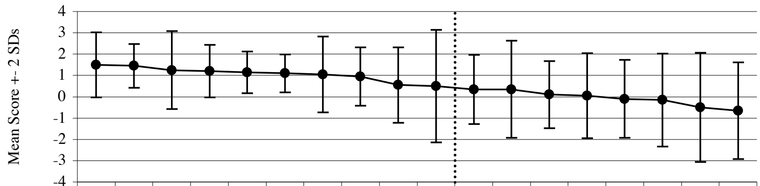
“F” Chord Directionality
(difference of fitness between prime [F > X] and target [X > F] conditions)

	C7	c	E7	Eb	Bb	B7	d	g	e	G7	D7	f	C	a	G	Ab	A7	F
DIFF	1,10	1,00	0,85	0,75	0,65	0,40	0,30	0,30	0,30	0,25	0,25	0,20	0,15	0,15	0,05	0,05	0,05	0,00
F > X	0,20	0,10	0,20	0,75	0,90	-0,90	1,50	0,60	0,50	1,30	0,80	0,35	1,65	1,10	1,50	1,10	0,45	1,00
X > F	1,30	1,10	1,05	1,50	1,55	-0,50	1,20	0,90	0,80	1,05	1,05	0,55	1,50	0,95	1,45	1,05	0,50	1,00

e) G major triad ("G")

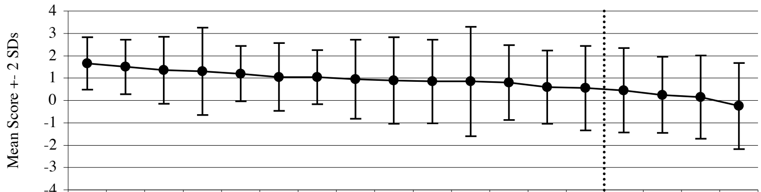
Figure 22. From top to bottom: "*G*" *chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of* "*G*" *chord as a prime and a target*, and "*G*" *chord directionality*, showing the difference of fitness between prime and target conditions.

G > X



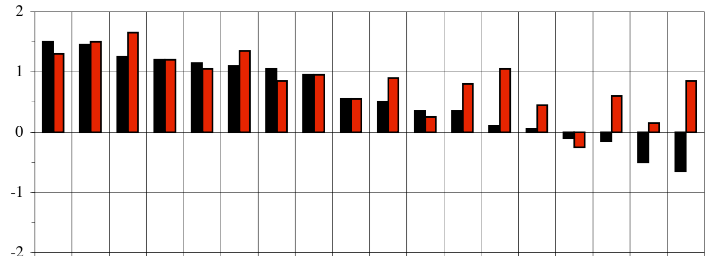
	a	F	C	G	Bb	d	A7	G7	E7	e	Ab	D7	Eb	g	B7	C7	f	c
Series1	1,50	1,45	1,25	1,20	1,15	1,10	1,05	0,95	0,55	0,50	0,35	0,35	0,10	0,05	-0,10	-0,15	-0,50	-0,65

X > G



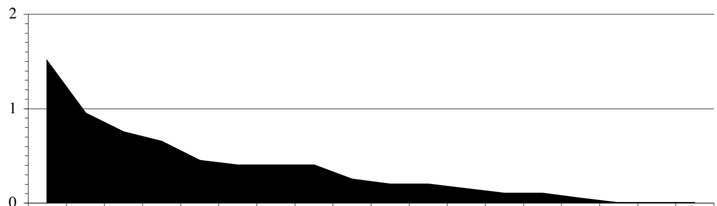
	C	F	d	a	G	Bb	Eb	G7	e	A7	c	D7	C7	E7	g	Ab	f	B7
Series1	1,65	1,50	1,35	1,30	1,20	1,05	1,05	0,95	0,90	0,85	0,85	0,80	0,60	0,55	0,45	0,25	0,15	-0,25

Fitness of "G" Chord as a Prime [G > X] and a Target [X > G]



	a	F	C	G	Bb	d	A7	G7	E7	e	Ab	D7	Eb	g	B7	C7	f	c
G > X	1,50	1,45	1,25	1,20	1,15	1,10	1,05	0,95	0,55	0,50	0,35	0,35	0,10	0,05	-0,10	-0,15	-0,50	-0,65
X > G	1,30	1,50	1,65	1,20	1,05	1,35	0,85	0,95	0,55	0,90	0,25	0,80	1,05	0,45	-0,25	0,60	0,15	0,85

"G" Chord Directionality
(difference of fitness between prime [G > X] and target [X > G] conditions)

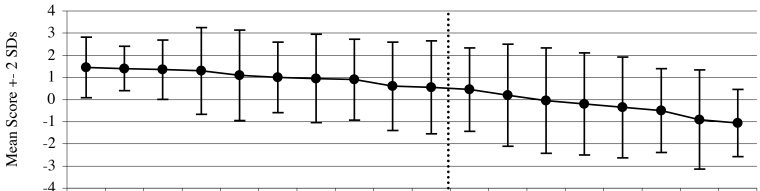


	c	Eb	C7	f	D7	C	e	g	d	a	A7	B7	Ab	Bb	F	G	G7	E7
DIFF	1,50	0,95	0,75	0,65	0,45	0,40	0,40	0,40	0,25	0,20	0,20	0,15	0,10	0,10	0,05	0,00	0,00	0,00
G > X	-0,65	0,10	-0,15	-0,50	0,35	1,25	0,50	0,05	1,10	1,50	1,05	-0,10	0,35	1,15	1,45	1,20	0,95	0,55
X > G	0,85	1,05	0,60	0,15	0,80	1,65	0,90	0,45	1,35	1,30	0,85	-0,25	0,25	1,05	1,50	1,20	0,95	0,55

f) A minor triad ("a")

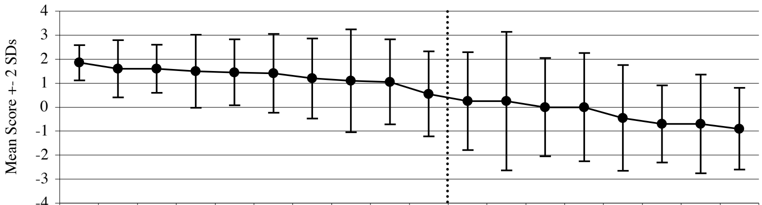
Figure 23. From top to bottom: *"a" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "a" chord as a prime and a target*, and *"a" chord directionality*, showing the difference of fitness between prime and target conditions.

a > X



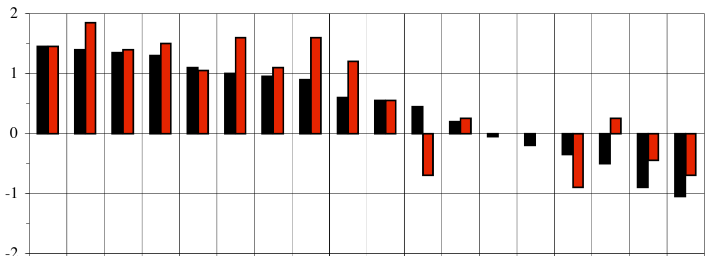
	a	C	e	G	D7	E7	F	d	G7	Bb	Ab	A7	B7	f	Eb	C7	g	c
Series1	1,45	1,40	1,35	1,30	1,10	1,00	0,95	0,90	0,60	0,55	0,45	0,20	-0,05	-0,20	-0,35	-0,50	-0,90	-1,05

X > a



	C	d	E7	G	a	e	G7	F	D7	Bb	A7	C7	B7	f	g	Ab	c	Eb
Series1	1,85	1,60	1,60	1,50	1,45	1,40	1,20	1,10	1,05	0,55	0,25	0,25	0,00	0,00	-0,45	-0,70	-0,70	-0,90

Fitness of "a" Chord as a Prime [a > X] and a Target [X > a]



	a	C	e	G	D7	E7	F	d	G7	Bb	Ab	A7	B7	f	Eb	C7	g	c
a > X	1,45	1,40	1,35	1,30	1,10	1,00	0,95	0,90	0,60	0,55	0,45	0,20	-0,05	-0,20	-0,35	-0,50	-0,90	-1,05
X > a	1,45	1,85	1,40	1,50	1,05	1,60	1,10	1,60	1,20	0,55	-0,70	0,25	0,00	0,00	-0,90	0,25	-0,45	-0,70

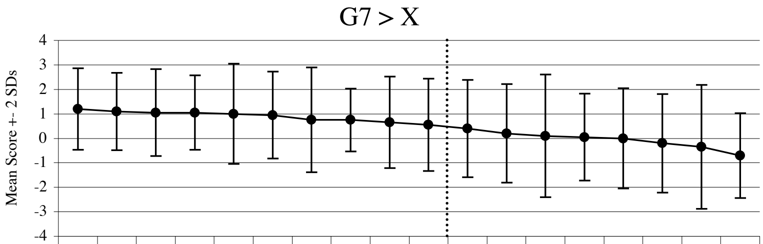
"a" Chord Directionality
(difference of fitness between prime [a > X] and target [X > a] conditions)

	Ab	C7	d	E7	G7	Eb	C	g	c	G	f	F	D7	A7	B7	e	a	Bb
DIFF	1,15	0,75	0,70	0,60	0,60	0,55	0,45	0,45	0,35	0,20	0,20	0,15	0,05	0,05	0,05	0,05	0,00	0,00
a > X	0,45	-0,50	0,90	1,00	0,60	-0,35	1,40	-0,90	-1,05	1,30	-0,20	0,95	1,10	0,20	-0,05	1,35	1,45	0,55
X > a	-0,70	0,25	1,60	1,60	1,20	-0,90	1,85	-0,45	-0,70	1,50	0,00	1,10	1,05	0,25	0,00	1,40	1,45	0,55

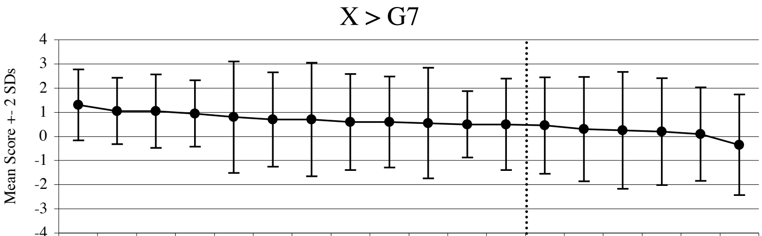
2. Secondary Dominants ("V7/X")

a) G Dominant Seventh ("G7")

Figure 24. From top to bottom: *"G7" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "G7" chord as a prime and a target*, and *"G7" chord directionality*, showing the difference of fitness between prime and target conditions.

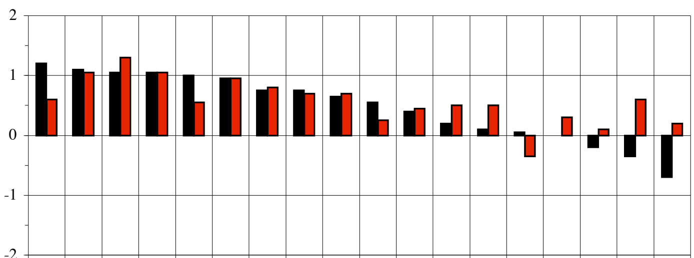


	a	d	F	G7	Bb	G	C	Eb	D7	Ab	C7	A7	e	B7	g	E7	c	f
Series1	1,20	1,10	1,05	1,05	1,00	0,95	0,75	0,75	0,65	0,55	0,40	0,20	0,10	0,05	0,00	-0,20	-0,35	-0,70



	F	d	G7	G	C	D7	Eb	a	c	Bb	A7	e	C7	g	Ab	f	E7	B7
Series1	1,30	1,05	1,05	0,95	0,80	0,70	0,70	0,60	0,60	0,55	0,50	0,50	0,45	0,30	0,25	0,20	0,10	-0,35

Fitness of "G7" Chord as a Prime [G7 > X] and a Target [X > G7]



	a	d	F	G7	Bb	G	C	Eb	D7	Ab	C7	A7	e	B7	g	E7	c	f
G7 > X	1,20	1,10	1,05	1,05	1,00	0,95	0,75	0,75	0,65	0,55	0,40	0,20	0,10	0,05	0,00	-0,20	-0,35	-0,70
X > G7	0,60	1,05	1,30	1,05	0,55	0,95	0,80	0,70	0,70	0,25	0,45	0,50	0,50	-0,35	0,30	0,10	0,60	0,20

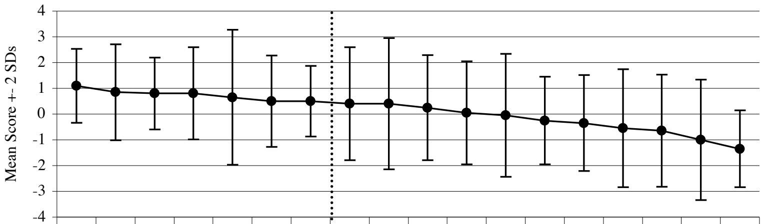
"G7" Chord Directionality
(difference of fitness between prime [G7 > X] and target [X > G7] conditions)

	c	f	a	Bb	e	B7	Ab	A7	g	E7	F	d	C	Eb	C7	D7	G7	G
DIFF	0,95	0,90	0,60	0,45	0,40	0,40	0,30	0,30	0,30	0,30	0,25	0,05	0,05	0,05	0,05	0,05	0,00	0,00
G7 > X	-0,35	-0,70	1,20	1,00	0,10	0,05	0,55	0,20	0,00	-0,20	1,05	1,10	0,75	0,75	0,40	0,65	1,05	0,95
X > G7	0,60	0,20	0,60	0,55	0,50	-0,35	0,25	0,50	0,30	0,10	1,30	1,05	0,80	0,70	0,45	0,70	1,05	0,95

b) A Dominant Seventh ("A7")

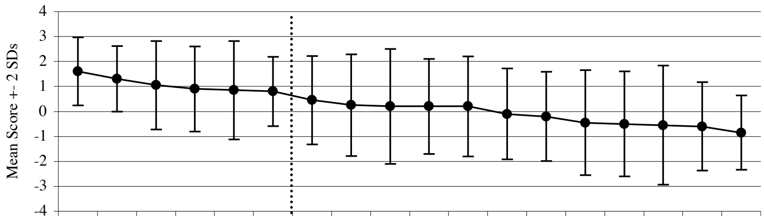
Figure 25. From top to bottom: "*A7*" *chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of* "*A7*" *chord as a prime and a target*, and "*A7*" *chord directionality*, showing the difference of fitness between prime and target conditions.

A7 > X



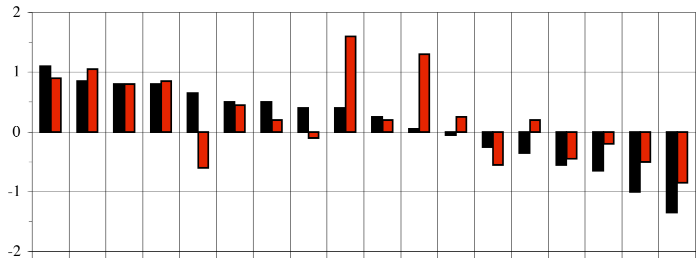
	d	G	A7	C	D7	F	G7	Bb	e	a	E7	B7	Ab	C7	Eb	g	f	c
Series1	1,10	0,85	0,80	0,80	0,65	0,50	0,50	0,40	0,40	0,25	0,05	-0,05	-0,25	-0,35	-0,55	-0,65	-1,00	-1,35

X > A7



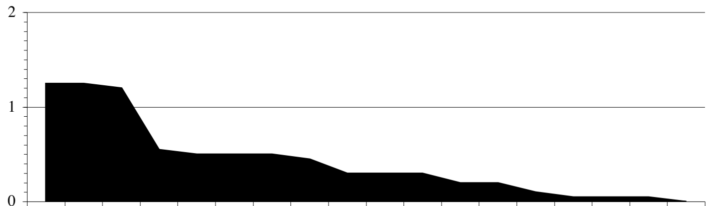
	e	E7	G	d	C	A7	F	B7	a	C7	G7	Bb	g	Eb	f	Ab	D7	c
Series1	1,60	1,30	1,05	0,90	0,85	0,80	0,45	0,25	0,20	0,20	0,20	-0,10	-0,20	-0,45	-0,50	-0,55	-0,60	-0,85

Fitness of “A7” Chord as a Prime [A7 > X] and a Target [X > A7]



	d	G	A7	C	D7	F	G7	Bb	e	a	E7	B7	Ab	C7	Eb	g	f	c
A7 > X	1,10	0,85	0,80	0,80	0,65	0,50	0,50	0,40	0,40	0,25	0,05	-0,05	-0,25	-0,35	-0,55	-0,65	-1,00	-1,35
X > A7	0,90	1,05	0,80	0,85	-0,60	0,45	0,20	-0,10	1,60	0,20	1,30	0,25	-0,55	0,20	-0,45	-0,20	-0,50	-0,85

“A7” Chord Directionality
(difference of fitness between prime [A7 > X] and target [X > A7] conditions)

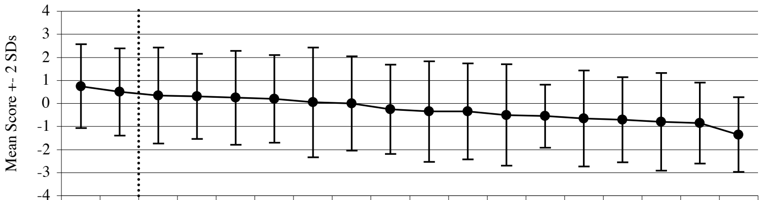


	D7	E7	e	C7	Bb	f	c	g	G7	B7	Ab	d	G	Eb	F	a	C	A7
DIFF	1,25	1,25	1,20	0,55	0,50	0,50	0,50	0,45	0,30	0,30	0,30	0,20	0,20	0,10	0,05	0,05	0,05	0,00
A7 > X	0,65	0,05	0,40	-0,35	0,40	-1,00	-1,35	-0,65	0,50	-0,05	-0,25	1,10	0,85	-0,55	0,50	0,25	0,80	0,80
X > A7	-0,60	1,30	1,60	0,20	-0,10	-0,50	-0,85	-0,20	0,20	0,25	-0,55	0,90	1,05	-0,45	0,45	0,20	0,85	0,80

c) B Dominant Seventh ("B7")

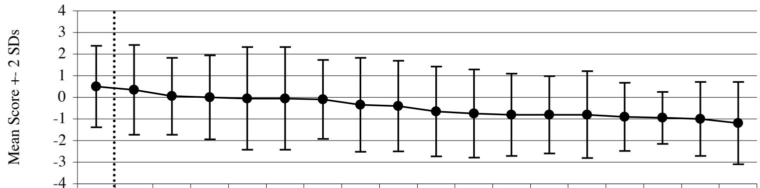
Figure 26. From top to bottom: *"B7" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "B7" chord as a prime and a target*, and *"B7" chord directionality*, showing the difference of fitness between prime and target conditions.

B7 > X



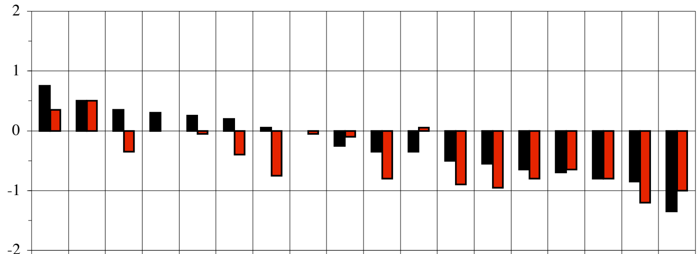
	e	B7	E7	C	A7	D7	Bb	a	G	Eb	G7	F	C7	Ab	d	g	f	c
Series1	0,75	0,50	0,35	0,30	0,25	0,20	0,05	0,00	-0,25	-0,35	-0,35	-0,50	-0,55	-0,65	-0,70	-0,80	-0,85	-1,35

X > B7



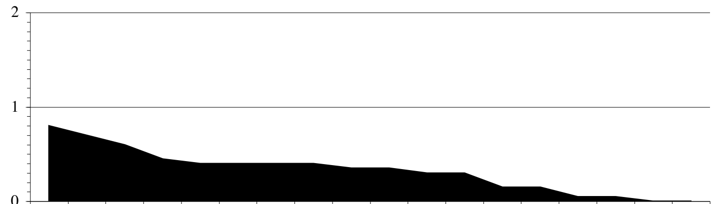
	B7	e	G7	C	A7	a	G	E7	D7	d	Bb	Ab	Eb	g	F	C7	c	f
Series1	0,50	0,35	0,05	0,00	-0,05	-0,05	-0,10	-0,35	-0,40	-0,65	-0,75	-0,80	-0,80	-0,80	-0,90	-0,95	-1,00	-1,20

Fitness of "B7" Chord as a Prime [B7 > X] and a Target [X > B7]



	e	B7	E7	C	A7	D7	Bb	a	G	Eb	G7	F	C7	Ab	d	g	f	c
B7 > X	0,75	0,50	0,35	0,30	0,25	0,20	0,05	0,00	-0,25	-0,35	-0,35	-0,50	-0,55	-0,65	-0,70	-0,80	-0,85	-1,35
X > B7	0,35	0,50	-0,35	0,00	-0,05	-0,40	-0,75	-0,05	-0,10	-0,80	0,05	-0,90	-0,95	-0,80	-0,65	-0,80	-1,20	-1,00

"B7" Chord Directionality
(difference of fitness between prime [B7 > X] and target [X > B7] conditions)

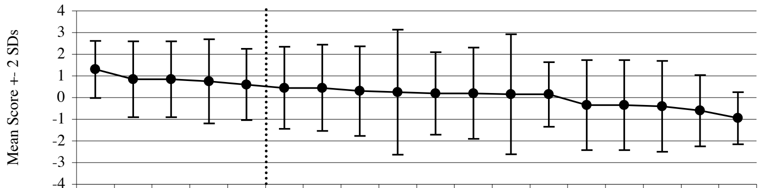


	Bb	E7	D7	Eb	e	G7	F	C7	f	c	C	A7	G	Ab	a	d	B7	g
DIFF	0,80	0,70	0,60	0,45	0,40	0,40	0,40	0,40	0,35	0,35	0,30	0,30	0,15	0,15	0,05	0,05	0,00	0,00
B7 > X	0,05	0,35	0,20	-0,35	0,75	-0,35	-0,50	-0,55	-0,85	-1,35	0,30	0,25	-0,25	-0,65	0,00	-0,70	0,50	-0,80
X > B7	-0,75	-0,35	-0,40	-0,80	0,35	0,05	-0,90	-0,95	-1,20	-1,00	0,00	-0,05	-0,10	-0,80	-0,05	-0,65	0,50	-0,80

d) C Dominant Seventh ("C7")

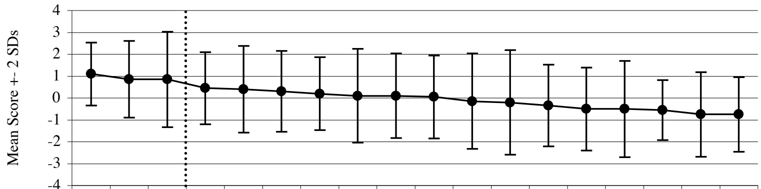
Figure 27. From top to bottom: *"C7" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "C7" chord as a prime and a target*, and *"C7" chord directionality*, showing the difference of fitness between prime and target conditions.

C7 > X



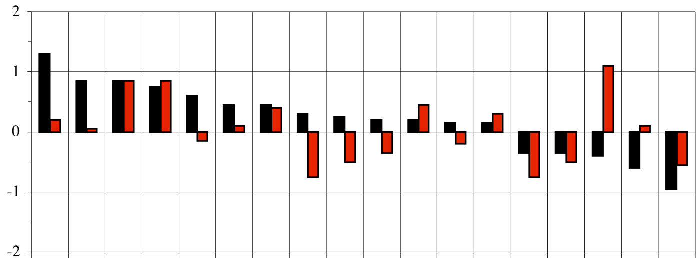
	F	Bb	C7	Eb	G	Ab	G7	d	a	A7	g	D7	f	E7	e	C	c	B7
Series1	1,30	0,85	0,85	0,75	0,60	0,45	0,45	0,30	0,25	0,20	0,20	0,15	0,15	-0,35	-0,35	-0,40	-0,60	-0,95

X > C7



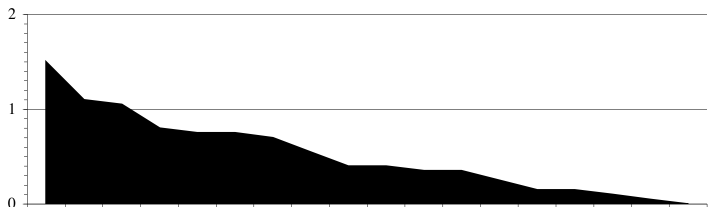
	C	C7	Eb	g	G7	f	F	Ab	c	Bb	G	D7	A7	a	e	B7	d	E7
Series1	1,10	0,85	0,85	0,45	0,40	0,30	0,20	0,10	0,10	0,05	-0,15	-0,20	-0,35	-0,50	-0,50	-0,55	-0,75	-0,75

Fitness of “C7” Chord as a Prime [C7 > X] and a Target [X > C7]



	F	Bb	C7	Eb	G	Ab	G7	d	a	A7	g	D7	f	E7	e	C	c	B7
C7 > X	1,30	0,85	0,85	0,75	0,60	0,45	0,45	0,30	0,25	0,20	0,20	0,15	0,15	-0,35	-0,35	-0,40	-0,60	-0,95
X > C7	0,20	0,05	0,85	0,85	-0,15	0,10	0,40	-0,75	-0,50	-0,35	0,45	-0,20	0,30	-0,75	-0,50	1,10	0,10	-0,55

“C7” Chord Directionality
(difference of fitness between prime [C7 > X] and target [X > C7] conditions)

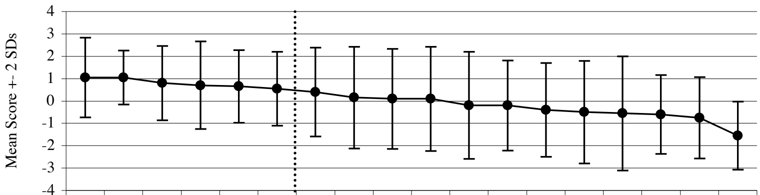


	C	F	d	Bb	G	a	c	A7	E7	B7	Ab	D7	g	f	e	Eb	G7	C7
DIFF	1,50	1,10	1,05	0,80	0,75	0,75	0,70	0,55	0,40	0,40	0,35	0,35	0,25	0,15	0,15	0,10	0,05	0,00
C7 > X	-0,40	1,30	0,30	0,85	0,60	0,25	-0,60	0,20	-0,35	-0,95	0,45	0,15	0,20	0,15	-0,35	0,75	0,45	0,85
X > C7	1,10	0,20	-0,75	0,05	-0,15	-0,50	0,10	-0,35	-0,75	-0,55	0,10	-0,20	0,45	0,30	-0,50	0,85	0,40	0,85

e) D Dominant Seventh ("D7")

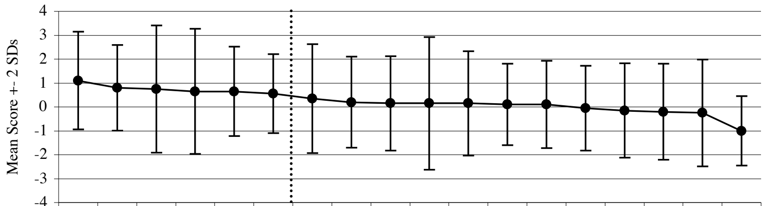
Figure 28. From top to bottom: "*D7*" *chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of* "*D7*" *chord as a prime and a target*, and "*D7*" *chord directionality*, showing the difference of fitness between prime and target conditions.

D7 > X



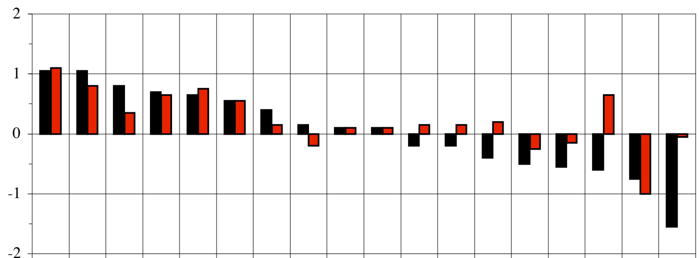
	a	F	G	G7	C	D7	Bb	e	Eb	g	C7	d	B7	f	E7	A7	Ab	c
Series1	1,05	1,05	0,80	0,70	0,65	0,55	0,40	0,15	0,10	0,10	-0,20	-0,20	-0,40	-0,50	-0,55	-0,60	-0,75	-1,55

X > D7



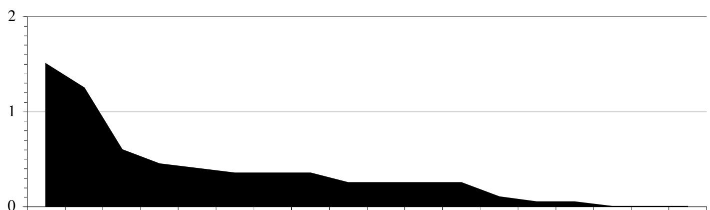
	a	F	C	A7	G7	D7	G	B7	Bb	C7	d	Eb	g	c	E7	e	f	Ab
Series1	1,10	0,80	0,75	0,65	0,65	0,55	0,35	0,20	0,15	0,15	0,15	0,10	0,10	-0,05	-0,15	-0,20	-0,25	-1,00

Fitness of "D7" Chord as a Prime [D7 > X] and a Target [X > D7]



	a	F	G	G7	C	D7	Bb	e	Eb	g	C7	d	B7	f	E7	A7	Ab	c
D7 > X	1,05	1,05	0,80	0,70	0,65	0,55	0,40	0,15	0,10	0,10	-0,20	-0,20	-0,40	-0,50	-0,55	-0,60	-0,75	-1,55
X > D7	1,10	0,80	0,35	0,65	0,75	0,55	0,15	-0,20	0,10	0,10	0,15	0,15	0,20	-0,25	-0,15	0,65	-1,00	-0,05

"D7" Chord Directionality
(difference of fitness between prime [D7 > X] and target [X > D7] conditions)

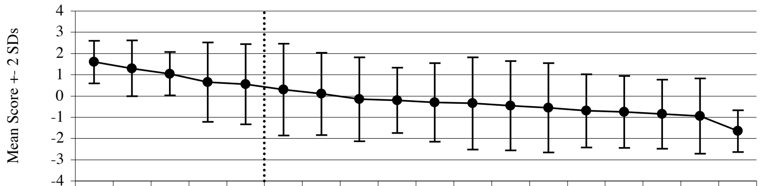


	c	A7	B7	G	E7	e	C7	d	F	Bb	f	Ab	C	a	G7	D7	Eb	g
DIFF	1,50	1,25	0,60	0,45	0,40	0,35	0,35	0,35	0,25	0,25	0,25	0,25	0,10	0,05	0,05	0,00	0,00	0,00
D7 > X	-1,55	-0,60	-0,40	0,80	-0,55	0,15	-0,20	-0,20	1,05	0,40	-0,50	-0,75	0,65	1,05	0,70	0,55	0,10	0,10
X > D7	-0,05	0,65	0,20	0,35	-0,15	-0,20	0,15	0,15	0,80	0,15	-0,25	-1,00	0,75	1,10	0,65	0,55	0,10	0,10

f) E Dominant Seventh ("E7")

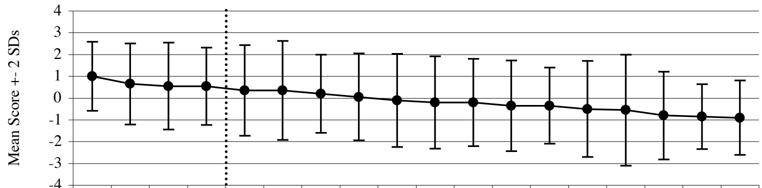
Figure 29. From top to bottom: "*E7*" *chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "E7" chord as a prime and a target*, and "*E7*" *chord directionality*, showing the difference of fitness between prime and target conditions.

E7 > X



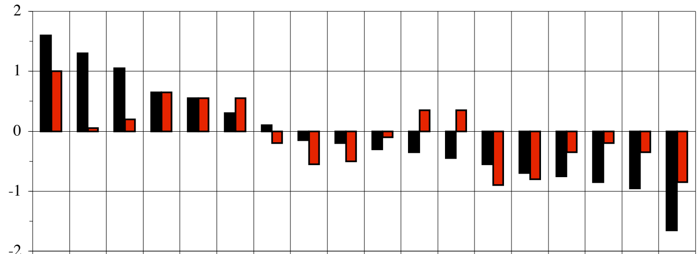
	a	A7	F	E7	G	C	G7	D7	Bb	d	B7	e	Ab	Eb	C7	f	g	c
Series1	1,60	1,30	1,05	0,65	0,55	0,30	0,10	-0,15	-0,20	-0,30	-0,35	-0,45	-0,55	-0,70	-0,75	-0,85	-0,95	-1,65

X > E7



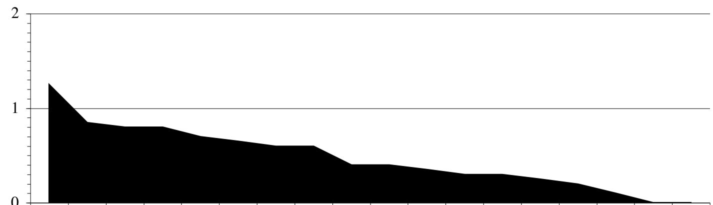
	a	E7	C	G	B7	e	F	A7	d	f	G7	C7	g	Bb	D7	Eb	c	Ab
Series1	1,00	0,65	0,55	0,55	0,35	0,35	0,20	0,05	-0,10	-0,20	-0,20	-0,35	-0,35	-0,50	-0,55	-0,80	-0,85	-0,90

Fitness of “E7” Chord as a Prime [E7 > X] and a Target [X > E7]



	a	A7	F	E7	G	C	G7	D7	Bb	d	B7	e	Ab	Eb	C7	f	g	c
E7 > X	1,60	1,30	1,05	0,65	0,55	0,30	0,10	-0,15	-0,20	-0,30	-0,35	-0,45	-0,55	-0,70	-0,75	-0,85	-0,95	-1,65
X > E7	1,00	0,05	0,20	0,65	0,55	0,55	-0,20	-0,55	-0,50	-0,10	0,35	0,35	-0,90	-0,80	-0,35	-0,20	-0,35	-0,85

“E7” Chord Directionality
(difference of fitness between prime [E7 > X] and target [X > E7] conditions)



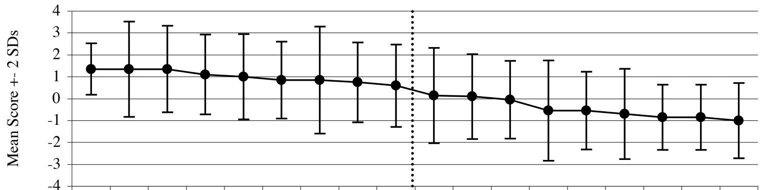
	A7	F	e	c	B7	f	a	g	D7	C7	Ab	G7	Bb	C	d	Eb	E7	G
DIFF	1,25	0,85	0,80	0,80	0,70	0,65	0,60	0,60	0,40	0,40	0,35	0,30	0,30	0,25	0,20	0,10	0,00	0,00
E7 > X	1,30	1,05	-0,45	-1,65	-0,35	-0,85	1,60	-0,95	-0,15	-0,75	-0,55	0,10	-0,20	0,30	-0,30	-0,70	0,65	0,55
X > E7	0,05	0,20	0,35	-0,85	0,35	-0,20	1,00	-0,35	-0,55	-0,35	-0,90	-0,20	-0,50	0,55	-0,10	-0,80	0,65	0,55

3. Modal interchange chords

a) C Minor Triad ("c")

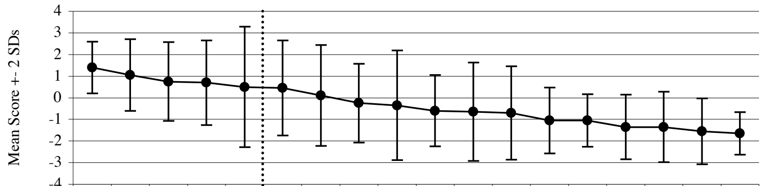
Figure 30. From top to bottom: *"c" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "c" chord as a prime and a target*, and *"c" chord directionality*, showing the difference of fitness between prime and target conditions.

c > X



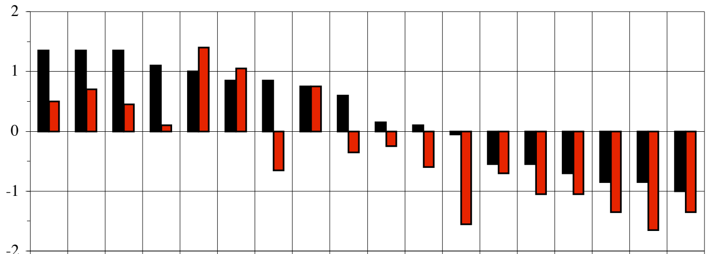
	Bb	Eb	g	F	Ab	f	G	c	G7	C	C7	D7	d	e	a	A7	E7	B7
Series1	1,35	1,35	1,35	1,10	1,00	0,85	0,85	0,75	0,60	0,15	0,10	-0,05	-0,55	-0,55	-0,70	-0,85	-0,85	-1,00

X > c



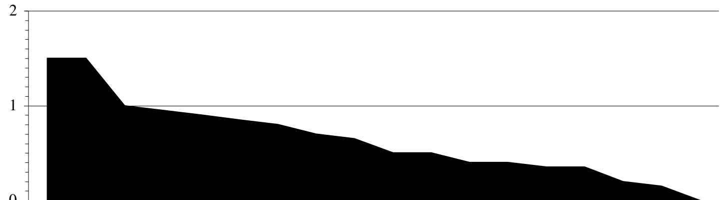
	Ab	f	c	Eb	Bb	g	F	C	G7	C7	G	d	a	e	A7	B7	D7	E7
Series1	1,40	1,05	0,75	0,70	0,50	0,45	0,10	-0,25	-0,35	-0,60	-0,65	-0,70	-1,05	-1,05	-1,35	-1,35	-1,55	-1,65

Fitness of "c" Chord as a Prime [c > X] and a Target [X > c]



	Bb	Eb	g	F	Ab	f	G	c	G7	C	C7	D7	d	e	a	A7	E7	B7
c > X	1,35	1,35	1,35	1,10	1,00	0,85	0,85	0,75	0,60	0,15	0,10	-0,05	-0,55	-0,55	-0,70	-0,85	-0,85	-1,00
X > c	0,50	0,70	0,45	0,10	1,40	1,05	-0,65	0,75	-0,35	-0,25	-0,60	-1,55	-0,70	-1,05	-1,05	-1,35	-1,65	-1,35

"c" Chord Directionality
(difference of fitness between prime [c > X] and target [X > c] conditions)

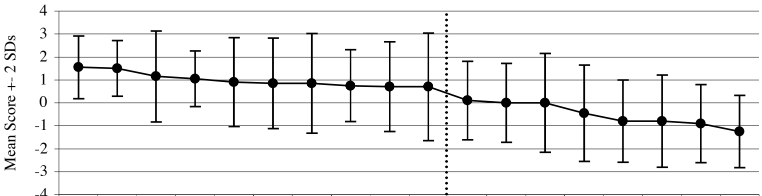


	G	D7	F	G7	g	Bb	E7	C7	Eb	e	A7	Ab	C	a	B7	f	d	c
DIFF	1,50	1,50	1,00	0,95	0,90	0,85	0,80	0,70	0,65	0,50	0,50	0,40	0,40	0,35	0,35	0,20	0,15	0,00
c > X	0,85	-0,05	1,10	0,60	1,35	1,35	-0,85	0,10	1,35	-0,55	-0,85	1,00	0,15	-0,70	-1,00	0,85	-0,55	0,75
X > c	-0,65	-1,55	0,10	-0,35	0,45	0,50	-1,65	-0,60	0,70	-1,05	-1,35	1,40	-0,25	-1,05	-1,35	1,05	-0,70	0,75

b) Eb Major Triad ("Eb")

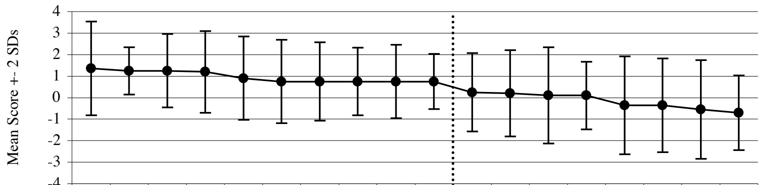
Figure 31. From top to bottom: *"Eb" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "Eb" chord as a prime and a target*, and *"Eb" chord directionality*, showing the difference of fitness between prime and target conditions.

Eb > X



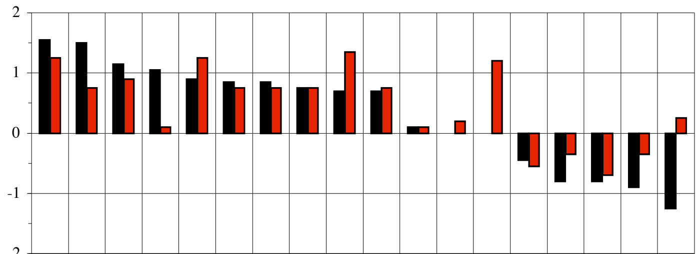
	Bb	F	g	G	Ab	C	C7	Eb	c	G7	D7	d	f	A7	B7	E7	a	e
Series1	1,55	1,50	1,15	1,05	0,90	0,85	0,85	0,75	0,70	0,70	0,10	0,00	0,00	-0,45	-0,80	-0,80	-0,90	-1,25

X > Eb



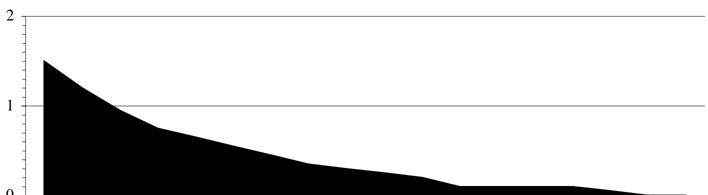
	c	Ab	Bb	f	g	C7	C	Eb	F	G7	e	d	D7	G	a	B7	A7	E7
Series1	1,35	1,25	1,25	1,20	0,90	0,75	0,75	0,75	0,75	0,75	0,25	0,20	0,10	0,10	-0,35	-0,35	-0,55	-0,70

Fitness of "Eb" Chord as a Prime [Eb > X] and a Target [X > Eb]



	Bb	F	g	G	Ab	C	C7	Eb	c	G7	D7	d	f	A7	B7	E7	a	e
Eb > X	1,55	1,50	1,15	1,05	0,90	0,85	0,85	0,75	0,70	0,70	0,10	0,00	0,00	-0,45	-0,80	-0,80	-0,90	-1,25
X > Eb	1,25	0,75	0,90	0,10	1,25	0,75	0,75	0,75	1,35	0,75	0,10	0,20	1,20	-0,55	-0,35	-0,70	-0,35	0,25

"Eb" Chord Directionality
(difference of fitness between prime [Eb > X] and target [X > Eb] conditions)

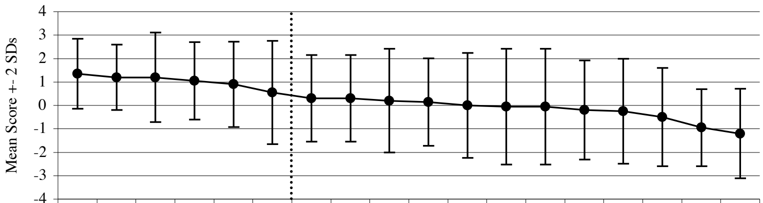


	e	f	G	F	c	a	B7	Ab	Bb	g	d	C	C7	A7	E7	G7	Eb	D7
DIFF	1,50	1,20	0,95	0,75	0,65	0,55	0,45	0,35	0,30	0,25	0,20	0,10	0,10	0,10	0,10	0,05	0,00	0,00
Eb > X	-1,25	0,00	1,05	1,50	0,70	-0,90	-0,80	0,90	1,55	1,15	0,00	0,85	0,85	-0,45	-0,80	0,70	0,75	0,10
X > Eb	0,25	1,20	0,10	0,75	1,35	-0,35	-0,35	1,25	1,25	0,90	0,20	0,75	0,75	-0,55	-0,70	0,75	0,75	0,10

c) F Minor Triad ("f")

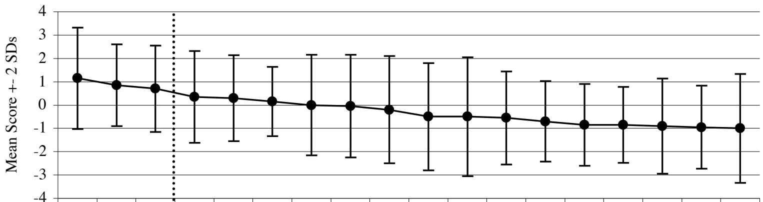
Figure 32. From top to bottom: *"f" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "f" chord as a prime and a target*, and *"f" chord directionality*, showing the difference of fitness between prime and target conditions.

f > X



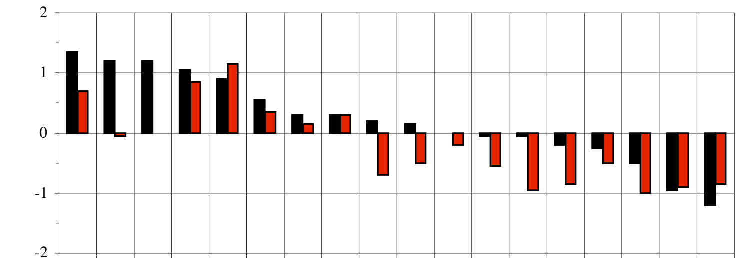
	Bb	C	Eb	c	Ab	F	C7	f	G7	G	a	d	g	E7	D7	A7	e	B7
Series1	1,35	1,20	1,20	1,05	0,90	0,55	0,30	0,30	0,20	0,15	0,00	-0,05	-0,05	-0,20	-0,25	-0,50	-0,95	-1,20

X > f



	Ab	c	Bb	F	f	C7	Eb	C	a	D7	G	d	G7	B7	E7	e	g	A7
Series1	1,15	0,85	0,70	0,35	0,30	0,15	0,00	-0,05	-0,20	-0,50	-0,50	-0,55	-0,70	-0,85	-0,85	-0,90	-0,95	-1,00

Fitness of "f" Chord as a Prime [f > X] and a Target [X > f]



	Bb	C	Eb	c	Ab	F	C7	f	G7	G	a	d	g	E7	D7	A7	e	B7
f > X	1,35	1,20	1,20	1,05	0,90	0,55	0,30	0,30	0,20	0,15	0,00	-0,05	-0,05	-0,20	-0,25	-0,50	-0,95	-1,20
X > f	0,70	-0,05	0,00	0,85	1,15	0,35	0,15	0,30	-0,70	-0,50	-0,20	-0,55	-0,95	-0,85	-0,50	-1,00	-0,90	-0,85

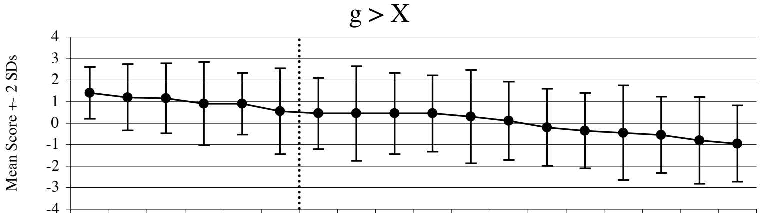
"f" Chord Directionality
(difference of fitness between prime [f > X] and target [X > f] conditions)

	C	Eb	G7	g	Bb	G	E7	d	A7	B7	Ab	D7	c	F	a	C7	e	f
DIFF	1,25	1,20	0,90	0,90	0,65	0,65	0,65	0,50	0,50	0,35	0,25	0,25	0,20	0,20	0,20	0,15	0,05	0,00
f > X	1,20	1,20	0,20	-0,05	1,35	0,15	-0,20	-0,05	-0,50	-1,20	0,90	-0,25	1,05	0,55	0,00	0,30	-0,95	0,30
X > f	-0,05	0,00	-0,70	-0,95	0,70	-0,50	-0,85	-0,55	-1,00	-0,85	1,15	-0,50	0,85	0,35	-0,20	0,15	-0,90	0,30

d) G Minor Triad ("g")

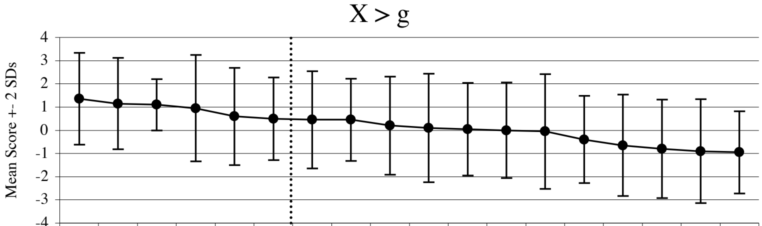
Figure 33. From top to bottom: "*g*" *chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of* "*g*" *chord as a prime and a target*, and "*g*" *chord directionality*, showing the difference of fitness between prime and target conditions.

g > X



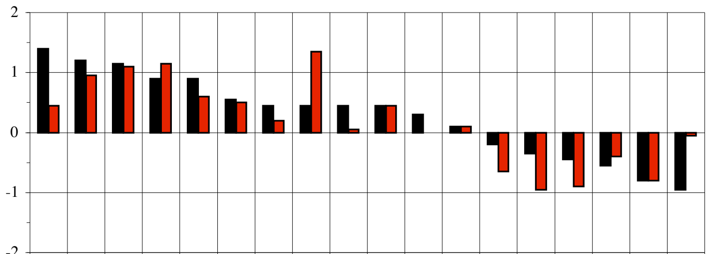
	d	Bb	C	Eb	F	Ab	C7	c	G	g	G7	D7	A7	E7	a	e	B7	f
Series1	1,40	1,20	1,15	0,90	0,90	0,55	0,45	0,45	0,45	0,45	0,30	0,10	-0,20	-0,35	-0,45	-0,55	-0,80	-0,95

X > g



	c	Eb	C	Bb	F	Ab	d	g	C7	D7	G	G7	f	e	A7	B7	a	E7
Series1	1,35	1,15	1,10	0,95	0,60	0,50	0,45	0,45	0,20	0,10	0,05	0,00	-0,05	-0,40	-0,65	-0,80	-0,90	-0,95

Fitness of "g" Chord as a Prime [g > X] and a Target [X > g]



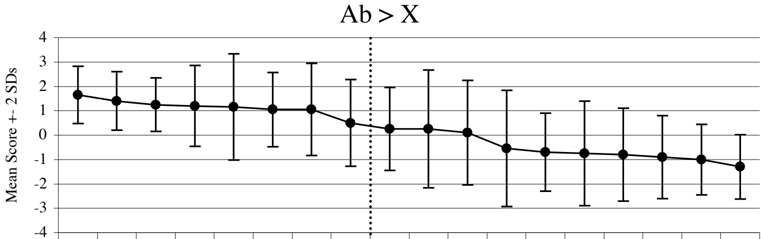
	d	Bb	C	Eb	F	Ab	C7	c	G	g	G7	D7	A7	E7	a	e	B7	f
g > X	1,40	1,20	1,15	0,90	0,90	0,55	0,45	0,45	0,45	0,45	0,30	0,10	-0,20	-0,35	-0,45	-0,55	-0,80	-0,95
X > g	0,45	0,95	1,10	1,15	0,60	0,50	0,20	1,35	0,05	0,45	0,00	0,10	-0,65	-0,95	-0,90	-0,40	-0,80	-0,05

"g" Chord Directionality
(difference of fitness between prime [g > X] and target [X > g] conditions)

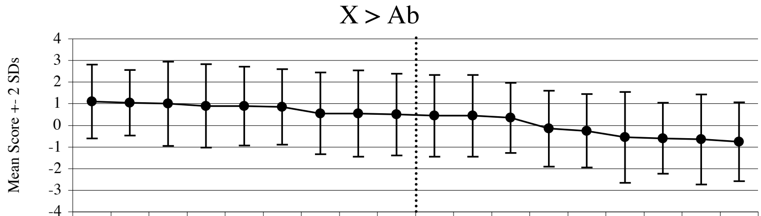
	d	c	f	E7	A7	a	G	F	G7	Bb	Eb	C7	e	Ab	C	g	D7	B7
DIFF	0,95	0,90	0,90	0,60	0,45	0,45	0,40	0,30	0,30	0,25	0,25	0,25	0,15	0,05	0,05	0,00	0,00	0,00
g > X	1,40	0,45	-0,95	-0,35	-0,20	-0,45	0,45	0,90	0,30	1,20	0,90	0,45	-0,55	0,55	1,15	0,45	0,10	-0,80
X > g	0,45	1,35	-0,05	-0,95	-0,65	-0,90	0,05	0,60	0,00	0,95	1,15	0,20	-0,40	0,50	1,10	0,45	0,10	-0,80

e) Ab Major Triad ("Ab")

Figure 34. From top to bottom: "*Ab*" *chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "Ab" chord as a prime and a target*, and "*Ab*" *chord directionality*, showing the difference of fitness between prime and target conditions.

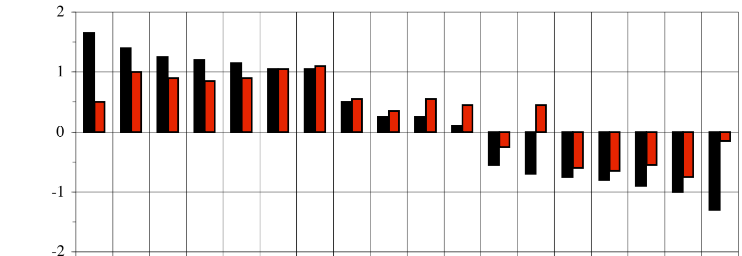


	Bb	c	Eb	C	f	Ab	F	g	G	G7	C7	A7	a	d	B7	E7	D7	e
Series1	1,65	1,40	1,25	1,20	1,15	1,05	1,05	0,50	0,25	0,25	0,10	-0,55	-0,70	-0,75	-0,80	-0,90	-1,00	-1,30



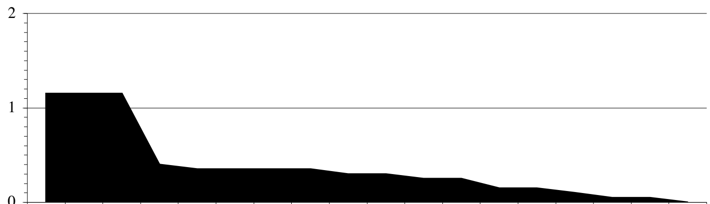
	F	Ab	c	Eb	f	C	G7	g	Bb	a	C7	G	e	A7	E7	d	B7	D7
Series1	1,10	1,05	1,00	0,90	0,90	0,85	0,55	0,55	0,50	0,45	0,45	0,35	-0,15	-0,25	-0,55	-0,60	-0,65	-0,75

Fitness of "Ab" Chord as a Prime [Ab > X] and a Target [X > Ab]



	Bb	c	Eb	C	f	Ab	F	g	G	G7	C7	A7	a	d	B7	E7	D7	e
■ Ab > X	1,65	1,40	1,25	1,20	1,15	1,05	1,05	0,50	0,25	0,25	0,10	-0,55	-0,70	-0,75	-0,80	-0,90	-1,00	-1,30
■ X > Ab	0,50	1,00	0,90	0,85	0,90	1,05	1,10	0,55	0,35	0,55	0,45	-0,25	0,45	-0,60	-0,65	-0,55	-0,75	-0,15

"Ab" Chord Directionality
(difference of fitness between prime [Ab > X] and target [X > Ab] conditions)

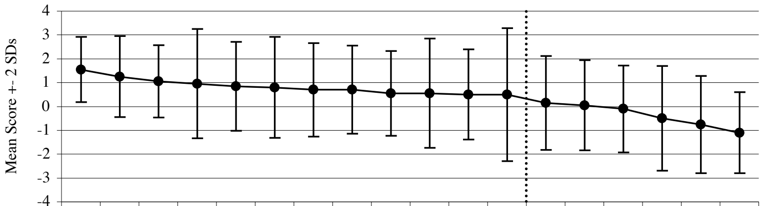


	Bb	a	e	c	Eb	C	C7	E7	G7	A7	f	D7	d	B7	G	F	g	Ab
DIFF	1,15	1,15	1,15	0,40	0,35	0,35	0,35	0,35	0,30	0,30	0,25	0,25	0,15	0,15	0,10	0,05	0,05	0,00
Ab > X	1,65	-0,70	-1,30	1,40	1,25	1,20	0,10	-0,90	0,25	-0,55	1,15	-1,00	-0,75	-0,80	0,25	1,05	0,50	1,05
X > Ab	0,50	0,45	-0,15	1,00	0,90	0,85	0,45	-0,55	0,55	-0,25	0,90	-0,75	-0,60	-0,65	0,35	1,10	0,55	1,05

f) Bb Major Triad ("Bb")

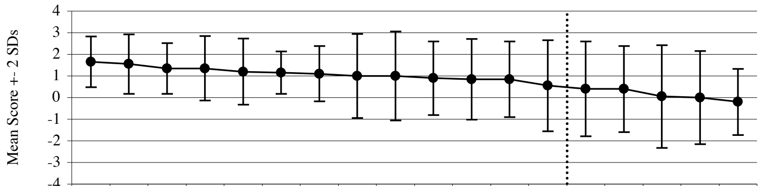
Figure 35. From top to bottom: *"Bb" chord fitness* (mean score +/- 2 standard deviations – chords to the left of the dashed line are valid primes/targets with positive [i.e. greater than negative or neutral] fitness means [≥ 0.50]), *Fitness of "Bb" chord as a prime and a target*, and *"Bb" chord directionality*, showing the difference of fitness between prime and target conditions.

Bb > X



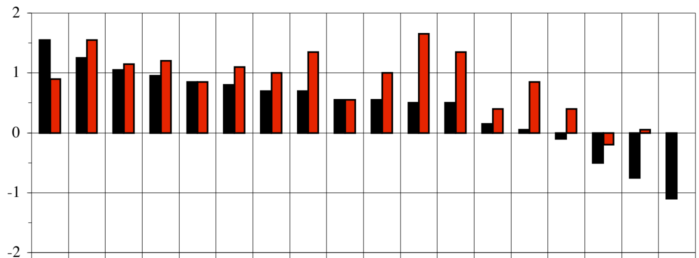
	F	Eb	G	g	Bb	d	C	f	a	G7	Ab	c	D7	C7	A7	E7	B7	e
Series1	1,55	1,25	1,05	0,95	0,85	0,80	0,70	0,70	0,55	0,55	0,50	0,50	0,15	0,05	-0,10	-0,50	-0,75	-1,10

X > Bb



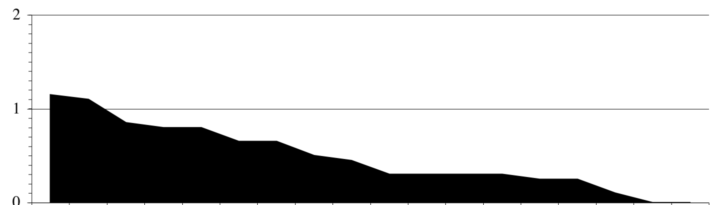
	Ab	Eb	c	f	g	G	d	C	G7	F	Bb	C7	a	A7	D7	B7	e	E7
Series1	1,65	1,55	1,35	1,35	1,20	1,15	1,10	1,00	1,00	0,90	0,85	0,85	0,55	0,40	0,40	0,05	0,00	-0,20

Fitness "Bb" Chord as a Prime [Bb > X] and a Target [X > Bb]



	F	Eb	G	g	Bb	d	C	f	a	G7	Ab	c	D7	C7	A7	E7	B7	e
Bb > X	1,55	1,25	1,05	0,95	0,85	0,80	0,70	0,70	0,55	0,55	0,50	0,50	0,15	0,05	-0,10	-0,50	-0,75	-1,10
X > Bb	0,90	1,55	1,15	1,20	0,85	1,10	1,00	1,35	0,55	1,00	1,65	1,35	0,40	0,85	0,40	-0,20	0,05	0,00

"Bb" Chord Directionality
(difference of fitness between prime [Bb > X] and target [X > Bb] conditions)

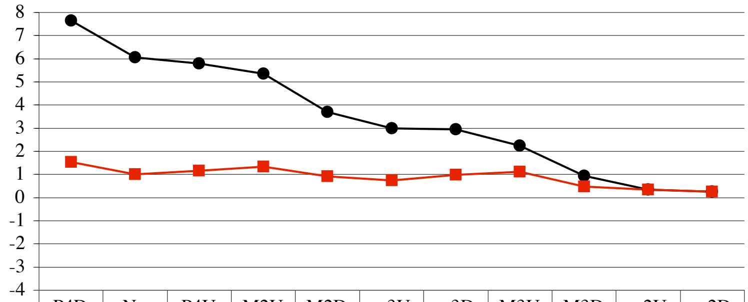


	Ab	e	c	C7	B7	F	f	A7	G7	Eb	d	C	E7	g	D7	G	Bb	a
DIFF	1,15	1,10	0,85	0,80	0,80	0,65	0,65	0,50	0,45	0,30	0,30	0,30	0,30	0,25	0,25	0,10	0,00	0,00
Bb > X	0,50	-1,10	0,50	0,05	-0,75	1,55	0,70	-0,10	0,55	1,25	0,80	0,70	-0,50	0,95	0,15	1,05	0,85	0,55
X > Bb	1,65	0,00	1,35	0,85	0,05	0,90	1,35	0,40	1,00	1,55	1,10	1,00	-0,20	1,20	0,40	1,15	0,85	0,55

Appendix F: Root Motion

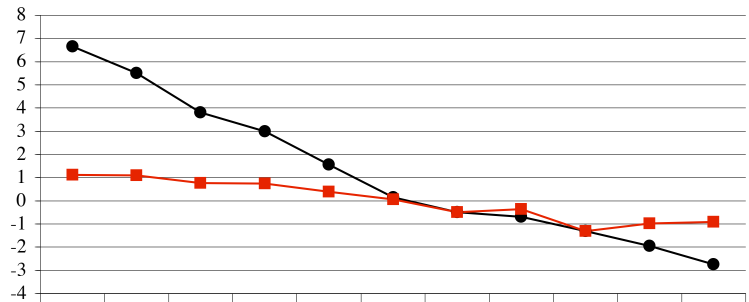
Figure 36. Progression from a major chord to another chord quality (fitness means).

Root Motion: Major to Major [X > X]



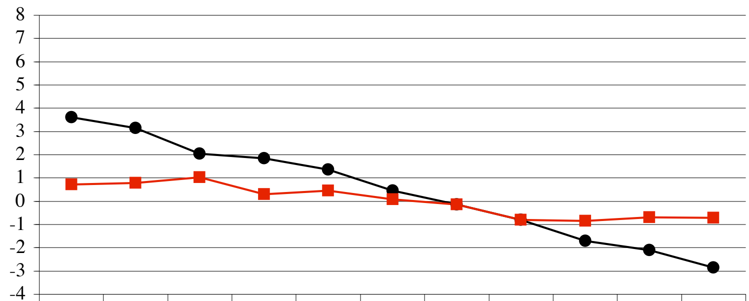
	P4D	No	P4U	M2U	M2D	m3U	m3D	M3U	M3D	m2U	m2D
Sums of Means	7,65	6,05	5,80	5,35	3,70	3,00	2,95	2,25	0,95	0,35	0,25
Means of Means	1,53	1,01	1,16	1,34	0,93	0,75	0,98	1,13	0,48	0,35	0,25

Root Motion: Major to Minor [X > x]



	m3D	M3U	M2U	P4D	m2D	No	M2D	P4U	M3D	m2U	TT
Sums of Means	6,65	5,50	3,80	3,00	1,55	0,15	-0,50	-0,70	-1,30	-1,95	-2,75
Means of Means	1,11	1,10	0,76	0,75	0,39	0,05	-0,50	-0,35	-1,30	-0,98	-0,92

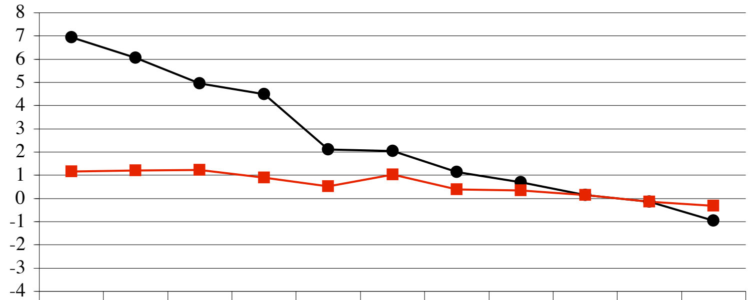
Root Motion: Major to Dominant [X > X7]



	m3D	M2U	No	M3U	P4D	m2D	P4U	m3U	M3D	m2U	TT
Sums of Means	3,60	3,15	2,05	1,85	1,35	0,45	-0,15	-0,80	-1,70	-2,10	-2,85
Means of Means	0,72	0,79	1,03	0,31	0,45	0,09	-0,15	-0,80	-0,85	-0,70	-0,71

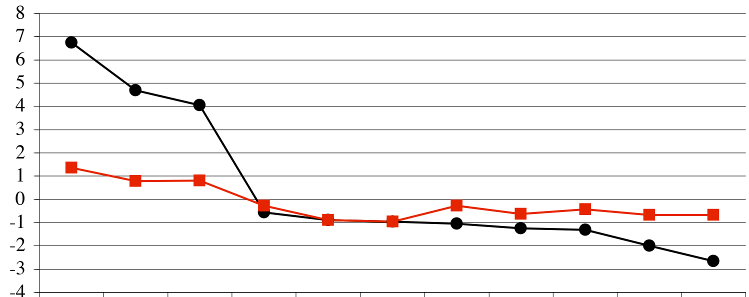
Figure 37. Progression from a minor chord to another chord quality (fitness means).

Root Motion: Minor to Major [x > X]



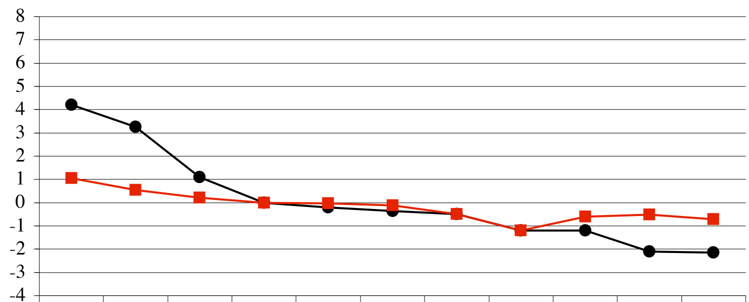
	m3U	M2D	P4U	M3D	m2U	P4D	No	m2D	M2U	M3U	TT
Sums of Means	6,95	6,05	4,95	4,50	2,10	2,05	1,15	0,70	0,15	-0,15	-0,95
Means of Means	1,16	1,21	1,24	0,90	0,53	1,03	0,38	0,35	0,15	-0,15	-0,32

Root Motion: Minor to Minor [x > x]



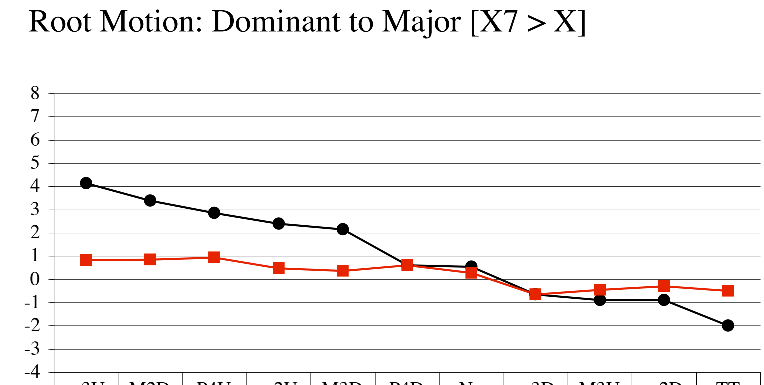
	P4D	No	P4U	M3U	m2U	m2D	M2U	M3D	m3D	m3U	M2D
Sums of Means	6,75	4,70	4,05	-0,55	-0,90	-0,95	-1,05	-1,25	-1,30	-2,00	-2,65
Means of Means	1,35	0,78	0,81	-0,28	-0,90	-0,95	-0,26	-0,63	-0,43	-0,67	-0,66

Root Motion: Minor to Dominant [x > X7]

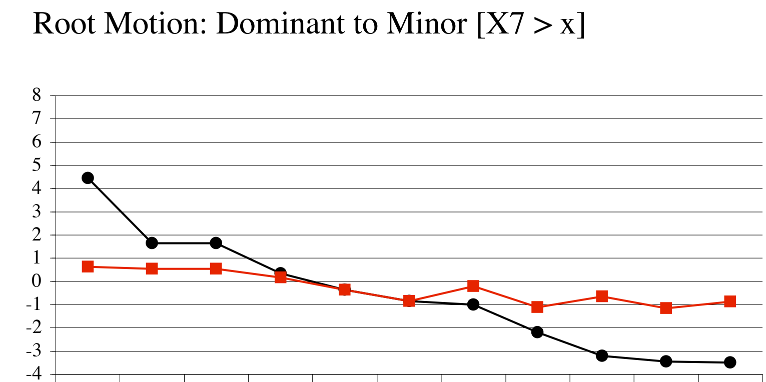


	P4U	P4D	No	m3U	M2U	M2D	M3D	TT	m2D	m3D	M3U
Sums of Means	4,20	3,25	1,10	0,00	-0,20	-0,35	-0,50	-1,20	-1,20	-2,10	-2,15
Means of Means	1,05	0,54	0,22	0,00	-0,04	-0,12	-0,50	-1,20	-0,60	-0,53	-0,72

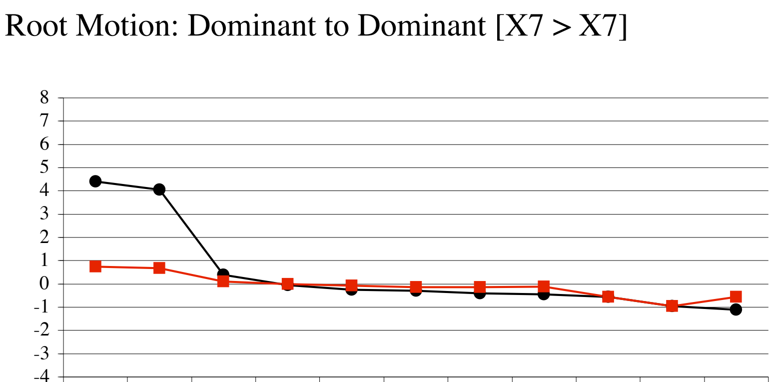
Figure 38. Progression from a dominant chord to another chord quality (fitness means).



	m3U	M2D	P4U	m2U	M3D	P4D	No	m3D	M3U	m2D	TT
Sums of Means	4,15	3,40	2,85	2,40	2,15	0,60	0,55	-0,65	-0,90	-0,90	-2,00
Means of Means	0,83	0,85	0,95	0,48	0,36	0,60	0,28	-0,65	-0,45	-0,30	-0,50



	P4U	M2U	P4D	m3D	M3U	TT	No	m2U	M2D	M3D	m3U
Sums of Means	4,45	1,65	1,65	0,35	-0,35	-0,85	-1,00	-2,20	-3,20	-3,45	-3,50
Means of Means	0,64	0,55	0,55	0,18	-0,35	-0,85	-0,20	-1,10	-0,64	-1,15	-0,88



	No	P4U	M2D	m3U	M2U	M3U	m3D	P4D	m2U	m2D	M3D
Sums of Means	4,40	4,05	0,40	-0,05	-0,25	-0,30	-0,40	-0,45	-0,55	-0,95	-1,10
Means of Means	0,73	0,68	0,10	-0,02	-0,06	-0,15	-0,13	-0,11	-0,55	-0,95	-0,55

Appendix G: Visualizations of common pop chord resolutions

1. Chord symbols (in C major)

Table 22.
*Diatonic triad > X (in **C** major).*

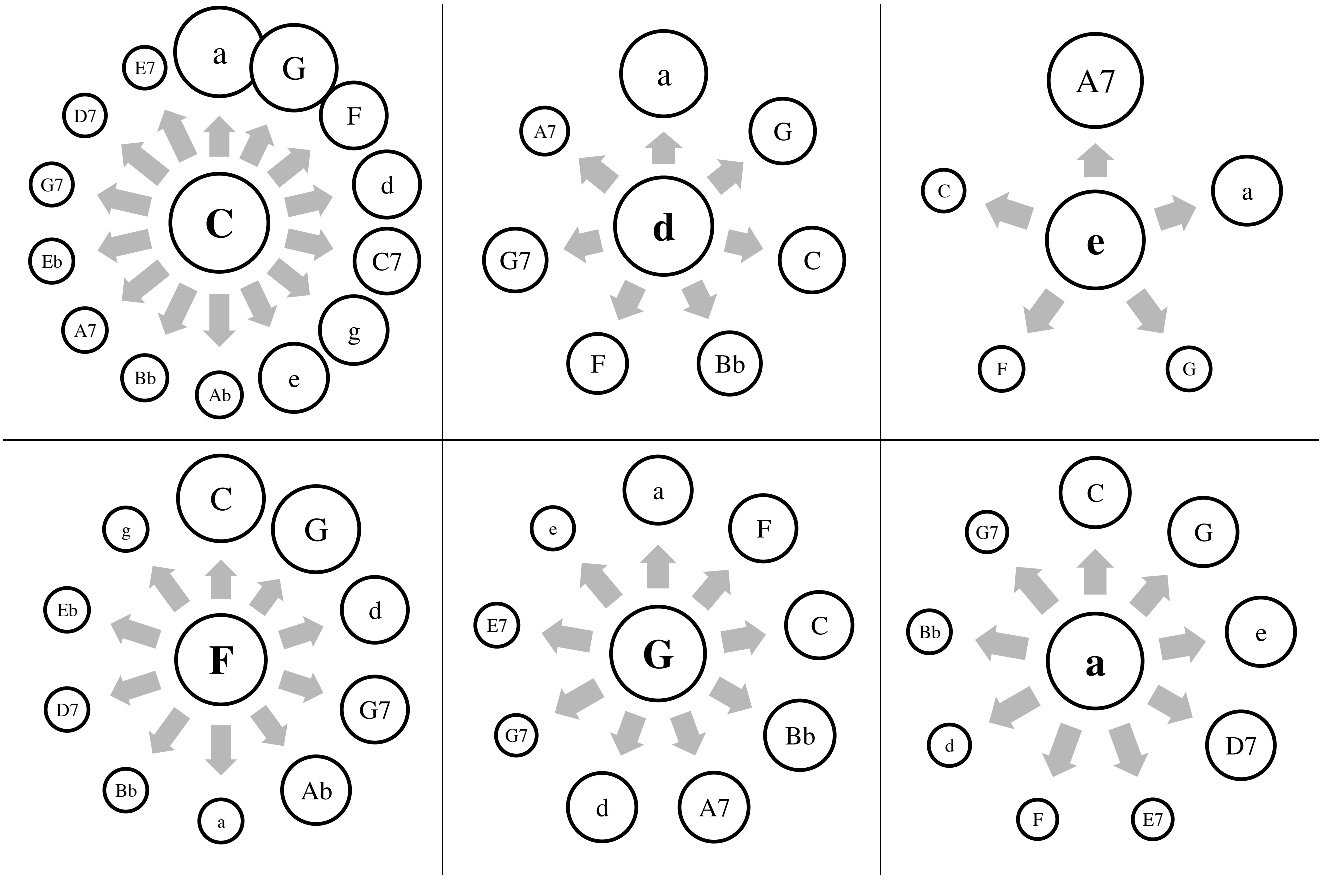
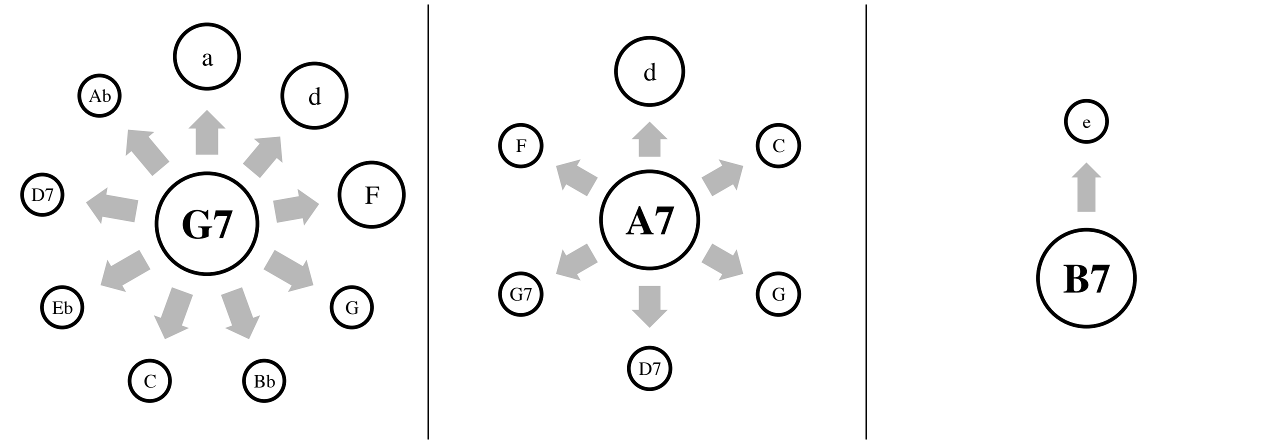


Table 23.
*Secondary dominant > X (in **C** major).*



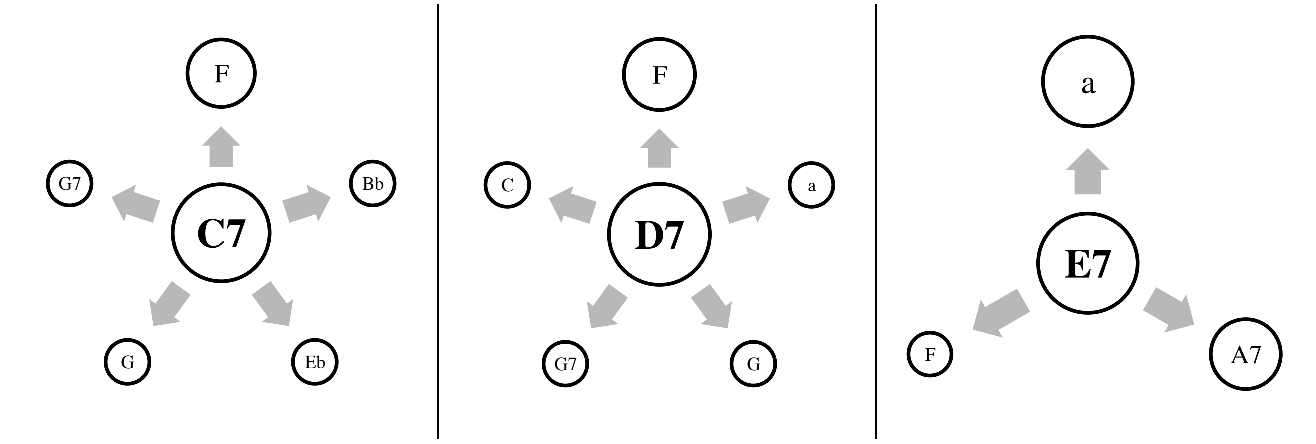
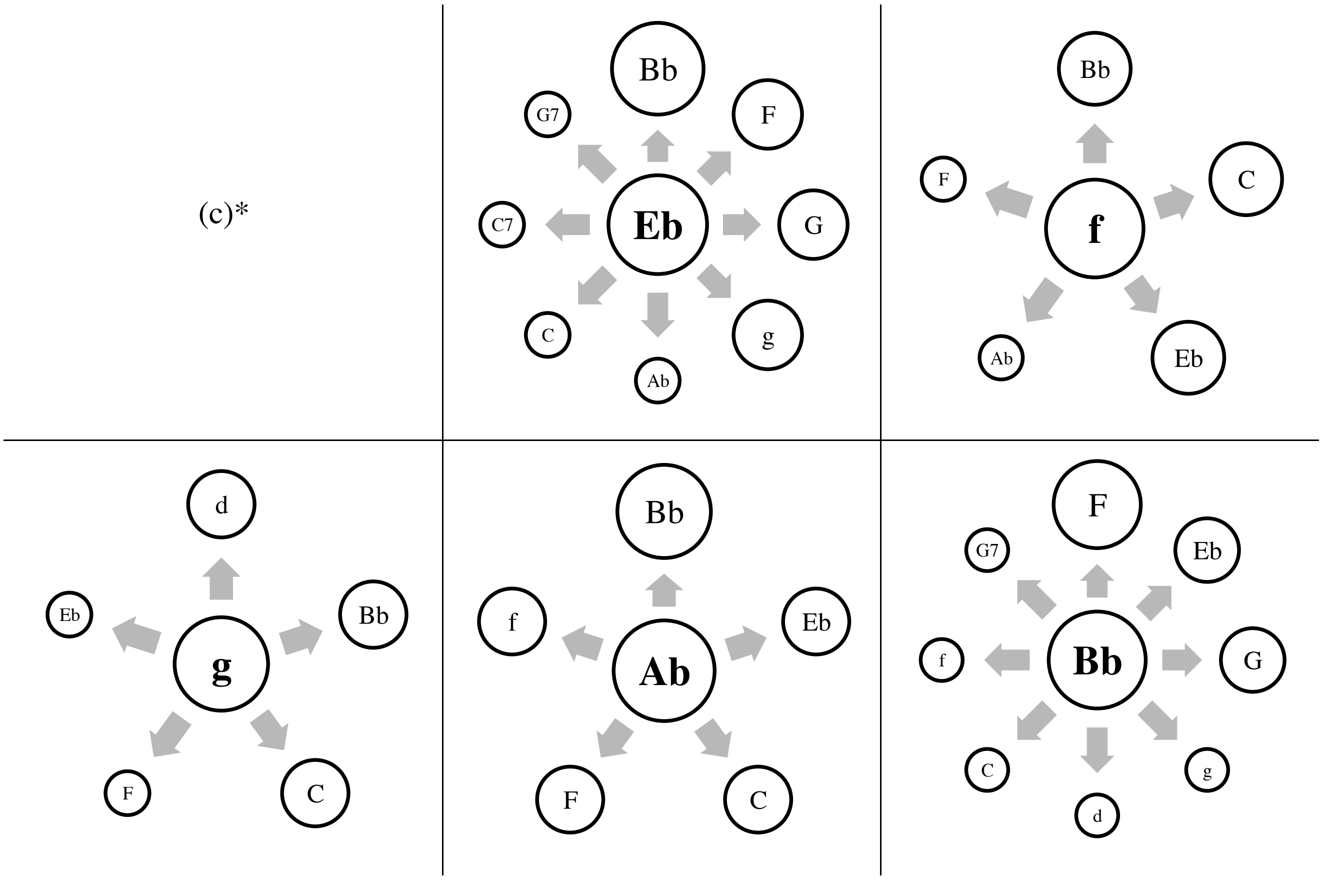


Table 24.
*Modal interchange chord > X (in **C** major).*



** Removed as not belonging to the key of **C** major.*

2. Chord degrees (in major keys)

Table 25.
Diatonic triad > X (in major keys).

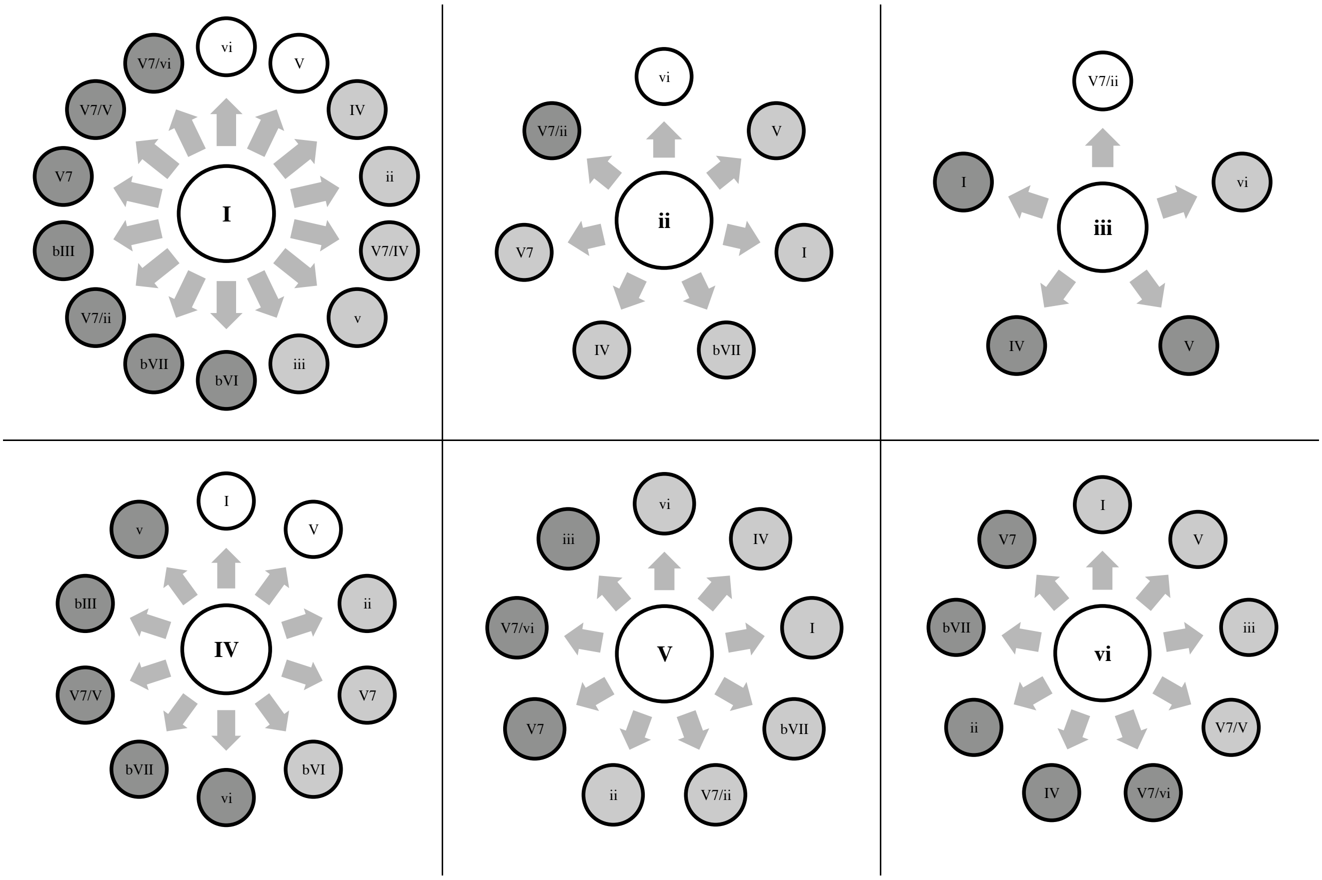
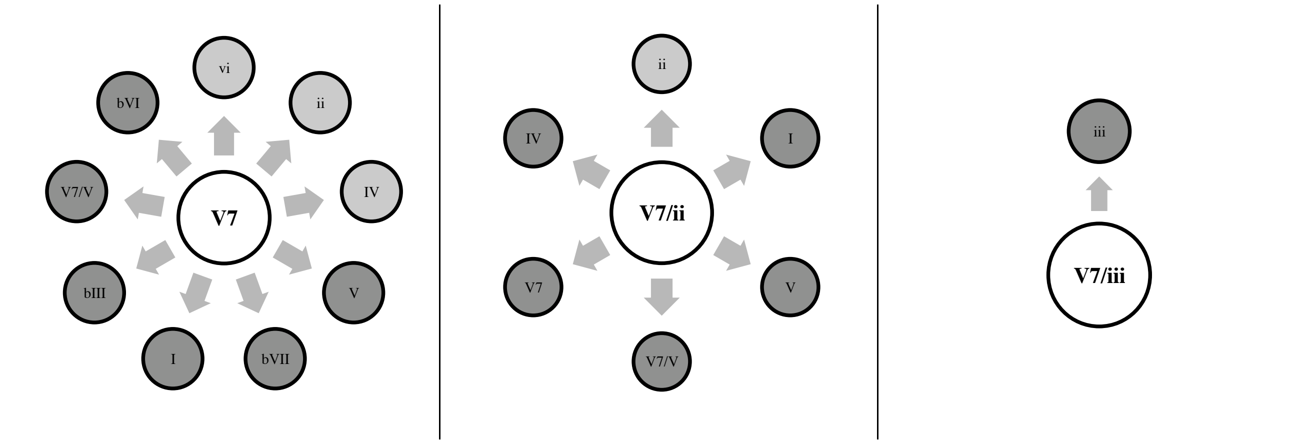


Table 26.
Secondary dominant > X (in major keys).



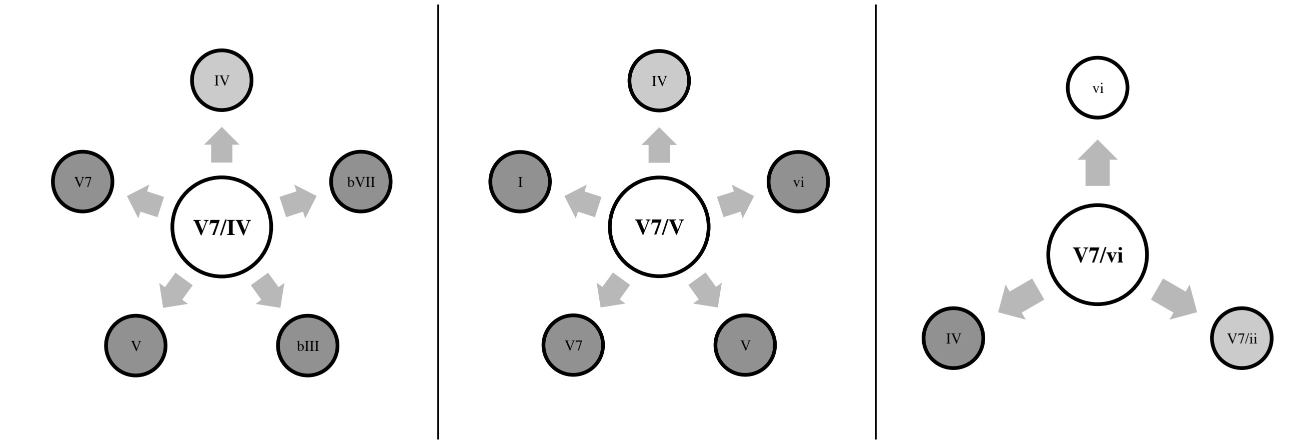
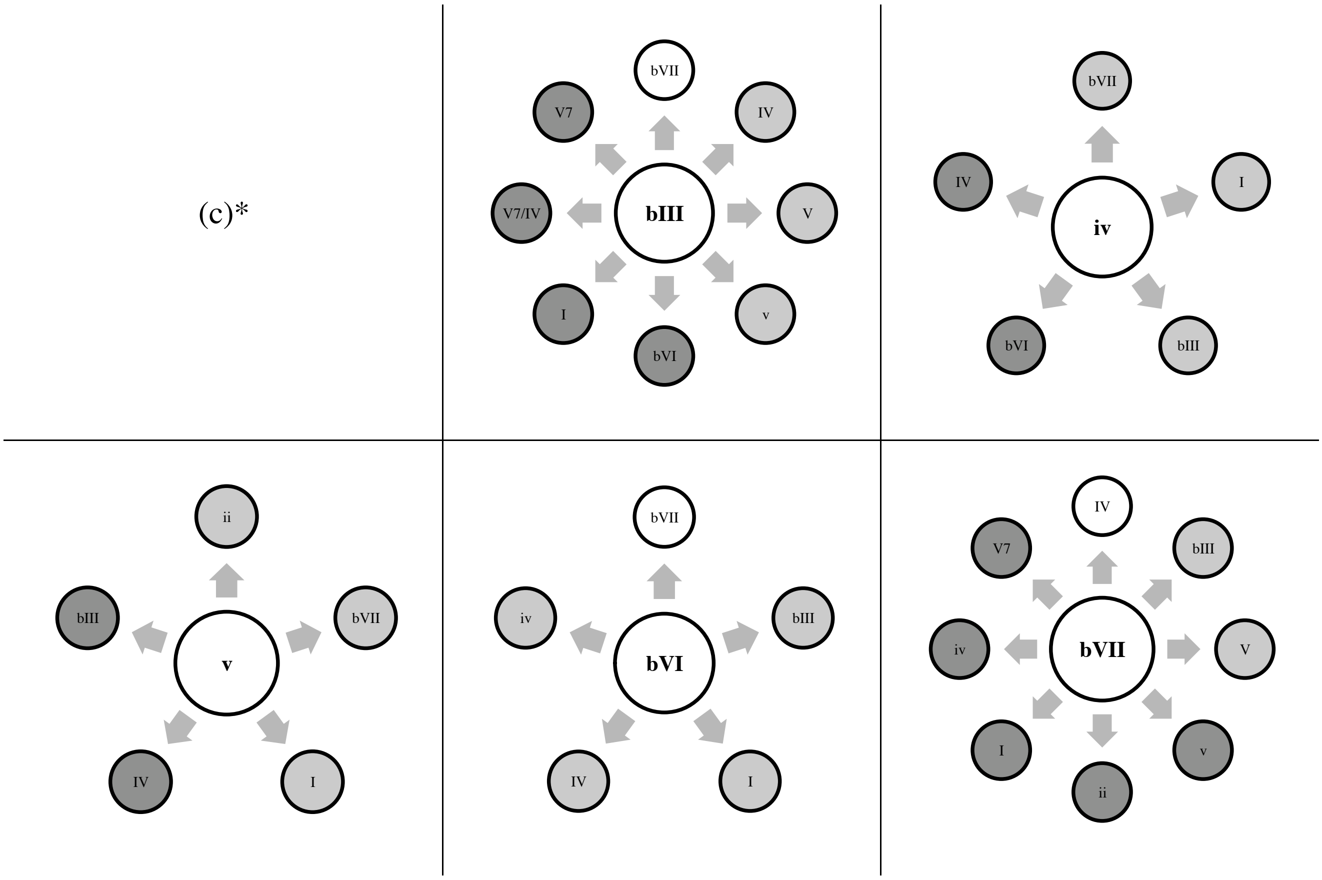


Table 27.
Modal interchange > X (in major keys).



** Removed as not belonging to a major key.*