The Creation of Consonance:
How Musical Context Influences Chord Perception

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Abstract

This PhD study investigates how our perception of musical chords, both in isolation and in musical context, is influenced and shaped by our knowledge of the tonal hierarchy and tonal syntax in terms of consonance/dissonance, pleasantness/unpleasantness, stability/instability, and relaxation/tension. Six experiments were conducted to gather behavioural data on the perception of chords from listeners with varying levels of musical training and experience. The first study is principally concerned with the influence of frequency of occurrence on the perception of twelve types of chord in isolation, including both triads and tetrads. It also examines to what extent factors besides frequency of occurrence, namely listener familiarity with the timbre in which chords are played and the acoustic features of chords, predict listener perception. The second and third studies concern the perception of chords in musical context. The second study focuses on musical contexts in which diminished and augmented chords appear, and on the harmonic functions of chords in short sequences of IV-V-I. Using sequences containing an augmented chord, the third study investigates the ways in which a non-diatonic tone can be anchored by its succeeding tone, and considers how the perception of these sequences is influenced by the harmonic function of its succeeding chord. These studies all reveal that the way in which chords and chord sequences are perceived is not completely predetermined by their acoustic, physical dimension. In addition, we impute on them a fluidity and elasticity as a result of our knowledge of the tonal hierarchy and tonal syntax in our musical schemata.

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Chapter 1

Introduction

The fascinating thing about intervals and chords is that, while from one perspective they are merely combinations of physical tones with different fundamental frequencies, these combinations of tones can have very different qualities and characters, and their consonance or dissonance is a key part of what shapes their character. Consonance and dissonance (C/D) help to make a piece of music more dramatic, tense or sweet, and the perception of consonance and dissonance makes the listening experience more pleasurable. One of the most striking examples of a chord's usage is the diminished seventh that appears in one of the most tense and dramatic scenes of J. S. Bach's *St Matthew's Passion*. The crowds of the chorus, consisting of two four-part choirs, form the diminished seventh chord of D#-F#-A-C as they scream out 'Barrabas!' This is the decisive and shocking moment when human beings committed a sin against God by choosing that the murderer Barabbas should be released and that Jesus should be executed. In order to convey the tension and awfulness of this moment in human history, Bach chose to use the diminished seventh chord. This chord consists of two tritones, which up until the 19th century was the most avoided of all musical intervals, and was branded the 'diabolus in musica (the devil in music)' due to its highly dissonant character (Drabkin, n.d.). The tritone consists of five semitones - only one fewer semitone than is in the perfect fifth, which is one of the most consonant intervals. This goes to show that even a small difference in interval size – as little as one semitone in this case - is capable of making a big difference in terms of consonance and dissonance.

There is a general consensus over which intervals or chords listeners perceive as consonant or dissonant. According to music theory (Piston, 1950), the unison, the octave, the perfect fifth, and the perfect fourth are all perfect consonances; the major sixth, minor thirds, minor sixth and major thirds are imperfect consonances; and intervals containing non-diatonic tones are dissonant. As for triads, major and minor chords are categorised as consonant, while diminished and augmented chords are dissonant because they contain non-diatonic intervals. Empirical studies have shown that listener perceptions of intervals and chords are generally consistent with this categorisation of the consonance and dissonance of intervals and chords (Bidelman & Krishnan, 2009, 2011; Cook & Fujisawa, 2006; Guernsey, 1928; Hutchinson & Knopff, 1978; Plomp & Levelt, 1965; Johnson-Laird, Kang, & Leong, 2012; Malmberg, 1918). Many empirical studies have sought an explanation for our perception of C/D that is grounded in the acoustic features of chords, such as roughness (Helmholtz, 1877/1954; Hutchinson & Kameoka, 1978, 1979; Kameoka & Kuriyagawa, 1969; Plompt & Levelt, 1965), fusion (Boring, 1942; DeWitt & Crowder, 1987; Schneider, 1997), and harmonicity (Cousineau, McDermott, & Peretz, 2012; McDermott, Lehr, & Oxenham, 2010; Tramo, Cariani, Delgutte, & Braida, 2001). Others have suggested, meanwhile, that factors such as musical context and the listener's musical schema also have a vital influence on C/D perception, especially on the C/D of chords that are heard as a part of music rather than in isolation. It has been reported that the extent to which a chord is heard as consonant or dissonant varies depending on the context in which it is heard (Gardner & Pickford, 1943, 1944; Roberts, 1986). However, which elements of context are pertinent and how they change the perception of C/D is as yet little known. The primary question this thesis explores is whether it is right to think of the consonance or dissonance of intervals and chords as not being absolute or fixed, but rather as fluid and elastic, and it seeks to answer this question by examining factors that may contribute to the flexibility of our C/D perception.

In attempting to address this question, this thesis should also fulfil three purposes. The first and main purpose is to shed light on the influence of non-acoustic features that have not yet been addressed in relation to C/D perception, such as: the influence of the frequency of occurrence of chords (Chapter 3); the influence of chord function (Chapter 4); and the influence of anchoring and tonal hierarchy (Chapter 5).

The second aim will be to examine the relationship between consonance and other concepts. For instance, consonance is often described and defined as any ‘pleasant’ sound (Tenny, 1980), while dissonance is considered to give rise to perceived and felt ‘tension’ (Lerdahl & Krumhansl, 1997; Parncutt & Hair, 2011). Consonance and dissonance are also related to ‘stability’ in the tonal hierarchy (Krumhansl, 1990; Bigand & Parncutt, 1997; Bigand, Parncutt, & Lerdahl, 1996). However, since we only have results from a handful of studies to date, we do not yet have enough empirical evidence to establish that these relationships are genuine and universal. Whether the perception of consonance is equivalent to or concurrent with the perception of pleasantness, stability and/or relaxation may depend on the type of chord, the musical context, or the individual listener. This question warrants further investigation.

Thirdly, this study aims to investigate the difference that musical expertise may make to C/D perception. This raises the old argument about whether the perception of C/D is primarily a matter of nature or nurture - in other words, whether C/D perception is a universal or culturally learned phenomenon. Some may argue that the perception of C/D is universal and intrinsic on account of the fact that C/D perception is shaped largely by the physical dimensions of sounds and by our auditory system. In support of the thesis that the perception of C/D is universal are studies that have reported that babies who have not been exposed to cultural influences nevertheless prefer consonance over dissonance (Trainor, Tsang, & Cheung, 2002; Trainor & Heinmiller, 1998; Zentner & Kagan, 1998). Other studies have found that Western and non-Western listeners (such as Japanese listeners) exhibit no differences in C/D perception (Butler & Daston, 1969) and neither do Western listeners and listeners from the Mafa tribe in Africa (Fritz , Jentschke, Gosselin, Sammler, & Peretz, 2009). On the other hand, certain other studies do reveal the influence of both cultural differences (Maher, 1976), and of the listener’s musical expertise (Brattico, Pallesen, Varyagina, Bailey, Anourova, Järvenpää, Eerola, & Tervaniemi, 2009; Itoh, Suwazono, & Nakada, 2010; McDermott, et al 2010; Roberts, 1986; Rogers, 2010; Schön, Regnault, Ystad, & Besson, 2005; Moreno & Bidelman, 2014) on the perception of C/D. Such studies lead to the view that C/D perception is sometimes shaped by the listener's cultural background and musical experience (Bidelman, 2013; Cazden, 1980). Recent studies suggest that C/D perception is probably the result of both nature and nurture; our perception of C/D is influenced both by the auditory and brain mechanisms that allow us to process auditory information, and by the extensive musical training that enhances our auditory and neural ability to discern specific aspects of sounds, and that enhances our sensitivity to musical syntax.

It may depend on the C/D in question whether or to what extent differences in musical expertise influence our perception of C/D. Differences in musical expertise may bring about more pronounced differences in the C/D perception of chords in tonal contexts than for isolated chords, because the C/D perception of chords in tonal contexts can be expected to involve a degree of implicit or explicit knowledge of tonal syntax, which musical training would enhance.

This thesis includes six experiments, all of which involve gathering behavioural data on listeners' C/D perceptions of different types of chords, both with and without musical context. The same experimental method was adopted throughout these experiments: participants were presented with musical stimuli consisting of a synthesised musical instrumental timbre, and were asked to rate these stimuli on a 7-point bipolar scale according to their consonance-dissonance, pleasantness-unpleasantness, stability-instability, and relaxation-tension. Participants were instructed to make 'perceived' evaluations: that is, to rate to what degree they perceived the musical stimuli to be pleasant/unpleasant, stable/unstable, and relaxed/tense, rather than rating their emotional experience of the stimuli.

Since the availability of methods for measuring objective physical and neural responses in research continues to expand, we are increasingly better able to establish more concrete explanations and theories for the process of C/D perception. For instance, psychophysiological data such as neural activity responses in the auditory nerves, the brainstem, and the auditory cortex, and neuroimaging data using fMRI scans have provided insights into how the brain and mind react to sound and music in general, and to C/D in particular (Bidelman & Krishnan, 2009, 2011; Bones, Hopkins, Krishnan, & Plack, 2014; Fishman, Volkov, Noh, Garell, Bakken, Arezzo, Howard, & Steinschneider, 2001; Itoh, Suwazono, & Nakada, 2010; Tramo, Cariani, Delgutte, & Braida, 2001). Notwithstanding the usefulness of these methods, this study will focus solely on behavioural data, for the following three reasons: behavioural data can teach us a lot about the experience of musical C/D perception; there is a lack of empirical evidence revealing the role of non-psychoacoustic factors in C/D perception; and the behavioural data presented here can serve as the foundation for future psychophysiological and/or neurophysiological research.

Thesis Outline

Chapter 2 summarises the literature relevant to C/D in order to consider the current state of our knowledge of this field. In this chapter, we discuss sensory and musical C/D, pleasantness, stability and tension, the influence of musical experience, and the plasticity of C/D perception.

Chapter 3 reports on the perception of chords in isolation in terms of C/D, pleasantness, stability, and relaxation. It has been found that more frequently occurring musical events tend to function as cognitive cues, which help listeners to establish the tonal relationship between tones and chords, and to understand the underlying structure of music

(Krumhansl, 1985, 2000). This study applies this frequency effect to the perception of chords in isolation, and examines how the frequency of a chord's occurrence, as well as its acoustic features, influences the way it is perceived. Three factors were considered: statistical data on the frequency of each chord's occurrence; the acoustic features of stimulus chords as extracted by MIR toolbox and Timbre toolbox; and the listener's familiarity with the two different instrumental timbres, piano and organ (Experiment 1). Behavioural data on the perception of twelve types of chord was collected (Experiment 2), and this behavioural data was analysed with reference to the three aforementioned factors to see whether they could help explain listeners' perceptions of chords. The relationship between the perception of the C/D of chords in isolation, and the perception of other factors - namely pleasantness, stability, and relaxation - was also examined. Further, the study examines whether there is any difference between the perceptions of listeners with differing levels of musical training.

Chapter 4 concerns the influence of harmonic function and context on the perception of chords, and considers the difference between chords perceived in isolation and in context. It is assumed that the C/D level of an acoustically identical chord can vary depending on the absence or presence of context (Cazden, 1980; Gardner & Pickford, 1943, 1944; Lundin, 1947; Roberts, 1986), and on its harmonic function when it appears in a context. This assumption derives from the observation that the listener often has an expectation about the 'right' context for a chord to appear, which is based on their knowledge of common harmonic progressions (Bigand and Pineau, 1996; Huron, 2006). Following on from these findings, this study contains two experiments that examine how listeners perceive diminished and augmented triads in terms of C/D and pleasantness when these triads appear in isolation (Experiment 3), and in context (Experiment 4). In Experiment 4, the same chords appeared in both common and uncommon positions in a harmonic context, which revealed how different harmonic functions influence the perception of diminished and augmented triads. Chord sequences consisting of three chords preceded by a scale to induce a sense of key were employed as musical stimuli. The sequences shared a common harmonic progression, VI-V-I. Half of the stimuli contained either a diminished or augmented triad in any of these three positions. Listeners were asked to rate the level of C/D and Pleasantness of each chord, and to rate each whole sequence on a 7-point scale. The effects of familiar harmonic function and of tonal hierarchy have been taken into consideration in the discussion of the results and findings. Also, data from Experiments 3 and 4 - on listeners' perceptions of chords in isolation and in context performing a variety of harmonic functions - were compared to assess the influence of context on the perception of C/D.

Chapter 5 investigates how the way in which the tone that succeeds the augmented fifth in an augmented triad influences the listener's perception of the short chord sequence in which the triad appears, in terms of C/D, pleasantness, stability, and relaxation. Previous studies have reported that the tone that follows the non-diatonic, dissonant tone plays an important role in the resolution of dissonance, and in determining perceptions of the melody (Bharucha, 1984, 1996). This study examines the influence of the way in which a dissonant tone is anchored by its succeeding tone on the perception of the chord sequence as a whole, and also the influence of the harmonic function of the chord to which the succeeding tone belongs.

Experiment 5 adopts the chord sequence I-V-I as musical stimuli, half of which contain an augmented triad in V. The inversions of the final chord, I, were manipulated in order to vary the way in which the augmented fifth (the top note of the middle chord) is anchored by the following note (the top note of the final chord). Experiment 6 adopts the same experimental method, but aims to discern the effects of harmony and anchoring, and to examine the interaction between these two by inserting chords with seven different harmonic functions into the third position of each sequence. The results and findings of Chapter 5 are concerned with how listeners' perceptions of the sequences are shaped by both horizontal and vertical aspects of harmony - the harmonic function of the final chord, and by the interval between the top notes of the middle and final chords.

Chapter 6 reviews and discusses the results and findings in the previous three chapters and seeks to draw appropriate conclusions from these. It also offers proposals for future studies.

Chapter 2

Literature Review

This work is a revised manuscript of a chapter, Pyschophysical and Psychological Approaches to Consonance and Dissonance. In ed. Ruggiero, G. & Bruni, D., *IL RITMO DELLA MENTE: La musica tra scienza cognitiva e psicoterapia*, Milan: Minesis, pp.47-69, 2015. Yuko Arthurs is the sole author.

2.1. Introduction

Consonance refers to the harmonious sounding of stimulating tones, and consonant sounds are often described as beautiful, pleasant, united, and smooth. Dissonance, meanwhile, refers to stimulating sound that has a rough quality, or to sounds that are unpleasant and inharmonious. Notions of consonance and dissonance (C/D) play an important role in our perception of music: they help us to understand the structure of music, and they influence our emotional response to it. A sense of C/D is vitally important when listening to a piece of music, as this not only enables one to understand the underlying harmonic context in which musical events develop, but it also makes the experience of listening more interesting, more dramatic, and sweeter. In fact, it is not too much to say that the perception of C/D forms the basis of musical listening, both in terms of understanding the structure of a musical work, and in terms of experiencing felt and perceived emotions.

Any listener with normal hearing ability will be able to judge almost instinctively whether a sound is consonant or dissonant, although there are differences between the judgements of musicians and non-musicians. This indicates that the discernment of consonance and dissonance is an ability that does not require any particular skills or special knowledge. Nevertheless, for researchers, explaining or establishing theories of the phenomenon of C/D has proved to be a challenging task. One of the biggest areas of contention surrounding the perception of C/D turns on whether it is an innate perception or a product of enculturation and learning. Researchers have sought an explanation for our perception of C/D in psychoacoustic accounts, which make reference to musical features such as frequency ratios, roughness, and harmonicity (Cousineau, McDermott, & Peretz, 2012; Helmholtz, 1877/1954; Hutchinson & Kameoka, 1978, 1979; Kameoka & Kuriyagawa, 1969; McDermott, Lehr, & Oxenham, 2010; Plompt & Levelt, 1965). Recent neurophysiological studies, meanwhile, provide vital evidence of the processes involved in C/D judgements at the cortical, subcortical, and peripheral auditory neural levels (Bidelman & Krishnan, 2009; Bones, Hopkins, Krishnan, & Plack, 2014; Fishman, Volkov, Noh, Garell, Bakken, Arezzo, Howard, & Steinschneider, 2001; Itoh, Suwazono, & Nakada, 2010; Tramo, Cariani, Delgutte, & Braida, 2001). These studies strongly indicate that our perception of C/D is highly constrained by the physical dimensions of sounds and by our own auditory systems. At the same time, others have offered explanations of C/D with reference to musical context, learning, and enculturation (Cazden, 1980; Gardener & Pickford, 1943, 1944; Lundin, 1947; Maher, 1976; Roberts, 1986), and these studies lend credence to the view that C/D perception is (at least partly) a product of learning and enculturation. This chapter outlines the main theories and studies of C/D. While these theories and studies touch on a diverse range of factors, from the sensory components of sound to the influence of the listener's musical schema on C/D perception, they all seek to shed light on the role of both nature and nurture in C/D perception.

2.1.1. Sensory C/D and musical C/D

Music theory categorises whether an interval or chord is consonant or dissonant. For instance, intervals such as octaves, perfect fifths, major and minor thirds, and major and minor sixths are considered consonant, while major and minor seconds, major and minor sevenths, major and minor ninths, and augmented and diminished intervals are categorised as dissonant (Piston, 1950). As for triads, major and minor triads are consonant, while diminished and augmented triads are considered dissonant on account of their containing dissonant intervals: the diminished fifth and the augmented fifth, respectively (Piston, 1950). Empirical studies reveal that listeners' C/D perception of intervals is consistent with the way in which music theory defines the consonance and dissonance of intervals (Guernsey, 1928; Malmberg, 1918). Regarding listeners' perceptions of chords, major triads are perceived as being most consonant, followed by minor triads, then diminished chords, and finally augmented chords are most dissonant of all (Bidelman and Krishnan, 2011; Cook & Fujisawa, 2006; Johnson-Laird, Kang, & Leong 2012; Roberts, 1986).

The type of C/D under consideration here is known as 'sensory C/D', as this categorisation of consonance and dissonance depends on the harmonic relationship between pitches. Sensory C/D concerns the sound of a chord or interval in isolation, and is largely defined in terms of the acoustical features or 'sonority' of a sound. Another type of C/D is musical C/D, which is sometimes referred to as harmonic C/D. Musical C/D is the consonance of an interval or chord as it appears within the flow of music. On the basis of Helmholtz (1877/1954), Terhardt (1977; 1984) suggests that musical consonance consists of two components: sensory consonance and harmony. Harmony has a different meaning from the one familiar from music theory, and represents the following three aspects: tonal affinity, compatibility, and root relationship/fundamental-note relation. Tonal affinity refers to the similarity between a note, chord, or melody and one that is an octave, fifth or fourth apart. Compatibility refers to a chord's ability to be inverted without it interfering with the harmoniousness of the overall sound. Lastly, root notes play an important role in identifying the function of a chord in a key, and because of this the root position plays an important role in influencing our perception of C/D. The perception of musical C/D, therefore, depends on the musical context in which the interval or chord is presented, as well as on its acoustical properties (Krumhansl, 1990; Terhardt, 1984).

2.2. Sensory C/D

2.2.1. Frequency ratios

C/D perception is to some extent an intrinsic ability, as our auditory system shapes and constrains our hearing ability. C/D researchers, adopting as they generally have a psychoacoustic point of view, have mainly focused on studying the acoustical features of sound that make it either consonant or dissonant. In ancient Greece, the Pythagoreans were the first to propose a relationship between the frequency ratios of a given pair of notes and the level of C/D when those two notes are sounded together. Their contention was that the simpler the frequency ratio between any two notes, the more consonant the sound produced would be. For example, the frequency ratio of the two notes that form an octave is 1:2, while for a fifth the ratio is 3:2: simple ratios such as these are predictors of consonant intervals, according to ancient Greek thought. On the other hand, a minor second and a tritone will be much more dissonant because of their more complex frequency ratios, which are 16:15 and 45:32 respectively.

2.2.2. Roughness

In the latter part of the 19^{th} century, Helmholtz (1877/1954) proposed that the perception of dissonance is attributable to the roughness of a sound, and that consonance can be defined as the absence of roughness. Roughness refers to the audible unpleasant beats that occur when two or more notes are played together. The rate of beating is equal to the difference between the frequencies of two tones when those tones are sinusoid. If the tones played are complex, then beating will also occur between the overtones. If the frequency ratio of two complex tones is simple then some of their overtones will overlap, thus making the beats non-audible. This overlapping, according to Helmholtz, makes us perceive sounds with simpler frequency ratios as more consonant. When two sinusoids share close frequencies then the beating—that is, the fluctuation in amplitude—will not be audible. However, the sound will become more unpleasant as the difference between the frequencies of the two sinusoids increases, with the maximum difference in frequencies lying between 30 and 40 Hz. This unpleasantness, which is called roughness, becomes progressively more pleasant and more consonant as the frequency difference between the two sinusoids moves either above or below the level of 40 Hz.

This sensation of roughness is related to the 'critical band' (Kameoka & Kuriyagawa, 1969; Plomp & Levelt, 1965). The critical band is a frequency bandwidth of an auditory filter in the cochlear, within which the presence of another tone can influence the perception of the original tone by auditory masking. The sounding of two complex tones tends to be perceived as most dissonant when the difference between the frequencies of those tones is 25% of the width of the critical band for those frequencies, while the sound becomes correspondingly less dissonant as the two frequencies move either further apart from, or closer together than, the 25% of the critical band. In other words, when two notes of an interval are too close in pitch, the interval is perceived more dissonant than when the frequencies of two notes have a 'comfortable' distance. This is because the hair neurons in the basilar membrane cannot distinguish between two notes whose frequencies are too close, and consequently some hair neurons will be excited by both of the notes, which results in harsh beating (Matthews, 1999).

On the basis of Helmholtz's original theory and Plomp and Levelt's (1965) development of it, Hutchinson and Knopff (1978) found that the perceived beating of the tonal spectrum could be quantified, and so were able to calculate dissonance factors for complex tones. This quantitative measure of the dissonance of complex tone intervals was termed 'acoustic dissonance'. Their ranking of acoustic dissonance from high to low was consistent with a C/D evaluation of intervals conducted by Malmberg (1918), in spite of differences in the timbres of the various stimuli used. Sethores (1999) and Vassilakis (2005,

2007) also devised a formula for the calculation of roughness. The rank order of dyads and chords according to their quantified roughness values are largely consistent with the perceived dissonance of these same dyads (Vassilakis, 2005) and chords (Johnson-Laird et al., 2012), indicating that calculated roughness is a good predictor of C/D perception.

However, some studies have rebutted the notion that roughness alone provides a sufficient explanation for C/D perception. It has been reported that listeners' C/D perception of dyads remains the same even after the occurrence of roughness has been minimised (Bidelman & Krishnan, 2009; Houtsma & Goldstein, 1972; McDermott et al., 2010). In the experiments contained within these studies, the two notes of each dyad were dichotically presented, which means that the two tones of each dyad were presented to different ears. Dichotic listening ensures that the amount of roughness will be reduced to a minimum since each cochlear processes only one tone, while diotic listening, in which both tones of the dyad are presented to both ears, is likely to trigger a sensation of roughness in the cochlear. However, it was found that dichotic listening did not generally alter the perception of C/D (Bidelman, 2013). In further support of the idea that roughness cannot by itself provide a sufficient explanation of C/D perception, Itoh et al. (2010) found that musicians' brain responses to different intervals distinguished consonance from dissonance even when roughness was not appreciable, indicating that C/D perception is attributable to other factors besides roughness.

2.2.3. Fusion

Another important theory concerning the C/D of sound is fusion. Fusion is a concept outlined by Carl Stumpf in the late 19th century (Boring, 1942; Schneider, 1997), which refers to the experience of hearing well-blended, simultaneous sounds that are perceived as one whole, coherent sound. Despite the coherence of sound, attentive listeners should still be able to distinguish each constituent tone in cases of fusion, and whether the listener hears the sound as a whole tone or as separated constituent tones depends on how they direct their attention. Stumpf observed that two tones tend to fuse better when they have simpler integer frequency ratios because their partials are more likely to coincide. In addition, the greater degree to which two tones are fused, the more consonant they will be also, while segregated sound that lacks fusion is more dissonant. According to Stump's fusion theory, an octave is the most fused interval, followed by the perfect fifth, the perfect fourth, and then major and minor thirds. An empirical study by DeWitt and Crowder (1987) shows that more consonant intervals—or intervals that are at least thought to be more consonant—are better fused than less consonant intervals. In their experiments, participants were asked to indicate whether the tone or interval they heard was one sound (fused) or two sounds (segregated). An octave was most likely to be heard as one sound, followed by the perfect fifth and then the perfect fourth, a result that is consistent with Stumpf's order of fused intervals.

However, Bregman (1990) argues that fusion is not equal to consonance, and insists on the need to distinguish between tones being 'heard as one' and being 'heard as smooth'. He even opposes Stumpf's view on fusion and consonance, and claims that sensory dissonance or roughness might be heard more strongly when tones are fused. This is because factors that enable us to hear different tones as fused – such as spectral proximity and harmonic concordance – also regulate perceived roughness. As with Bregman (1990), Huron (1991) also highlighted differences between fusion and consonance. By analysing sample data of interval prevalence from J. S. Bach's polyphonic music, Huron's (1991) study revealed that Bach used intervals that enhance tonal consonance, while at the same time avoiding intervals that promote fusion so as to prevent multiple voices being heard as integrated.

2.2.4. Harmonicity

The concept of fusion is related to the concept of harmonicity. Harmonicity refers to the degree of distance between the spectral frequency and its corresponding harmonic series (Parncutt, 1989). A harmonic series is a sequence of multiples that begins with the fundamental frequency. For instance, a complex tone whose fundamental frequency is 100Hz has a harmonic series of 200Hz, 400Hz, 800Hz, 1600Hz, and so on. A tone is harmonic when its partials form a similar pattern to its harmonic series. In the case of intervals, the more simple the frequency ratios of an interval are, the more harmonic that interval will be, since the partials of two simple notes coincide to a greater degree and thus produce more regular patterns (Gill & Purves, 2009). Additionally, partials of intervals with a simpler frequency ratio interact less, and this minimises beating, which is considered a cause of roughness.

Some studies have sought to demonstrate that harmonicity is a greater contributory factor to consonance perception than the absence of roughness. McDermott and his colleagues (2010) compared stimuli with and without beating, and both harmonic and inharmonic stimuli. Participants' ratings of the pleasantness of each interval and chord showed that they preferred stimuli without beating over those with beating, and harmonic stimuli over inharmonic ones. There was a strong correlation between pleasantness ratings and harmonicity, and a weak correlation between pleasantness ratings and the absence of roughness, indicating that harmonicity is a better predictor of consonance than is the absence of roughness. A study by Cousineau et al. (2012) likewise demonstrated that beating is a poor predictor of C/D by employing people with amusia as participants as well as people without the condition. They found that participants with amusia were not only able to detect intervals and chords with beating, but they also expressed a dislike for them. However, in contrast to those participants without amusia, they showed no preference for consonant or harmonic tones over more dissonant and inharmonic ones.

What we can see from studies concerning roughness and harmonicity is that it might not be the case that perceived sensory consonance and dissonance is created by the existence or absence of one particular factor; instead, it might be more accurately viewed as arising from the intermingling of a variety of acoustic features. As Parncutt and Hair (2011) say, consonance and dissonance may not be opposite ends of the same bipolar variable. Rather, consonance and dissonance may be phenomena that are promoted by different physical dimensions of intervals and chords, including harmonicity and roughness.

2.2.5. Neurophysiological evidence on harmonicity

Neurophysiological studies show the powerful influence harmonicity exerts on the perception of consonance. On the basis of the periodic information obtained from auditory nerve activity in the brainstem, Bidelman and Krishnan (2009) computed 'neural pitch salience'—'the neural analog of the primary behavioural correlate of consonance and dissonance'—in order to measure harmonicity. It was found that intervals and chords judged as consonant by listeners—such as the unison, the perfect fifth, and major and minor chords—trigger stronger neural activity in both the auditory nerve and the rostral brainstem, and have stronger computed hamonicity values (Bidelman and Krishnan, 2009, 2011; Bidelman and Heinz, 2011). Adapting the calculation method of neural pitch salience, Bones et al. (2014) calculated the strength of harmonicity by measuring the neural response in the brainstem, which they called 'harmonic salience'. They found that there was a strong correlation between harmonic salience represented in brainstem responses and listeners' perceptions of the pleasantness of dyads.

Bidelman (2013) suggests that a better understanding of pitch perception can help us to explain why we perceive more harmonic tones as more consonant. When sounds are presented to a listener, the vibration of the basilar membrane reflects the waveform of a sound. This information about the sound is transmitted to the listener's auditory nerves, and this in turn excites the neurons that transmit information about sound from the cochlea to the brainstem. The patterns of excited neuronal firing mirror the periodic information of the vibration of the basilar membrane, a phenomenon called 'phase-lock' (Plack, 2004). Consonant intervals and chords produce clearer and more synchronous phase-locking, with clearer periodic peaks than do dissonant chords (Tramo et al., 2001; Bidelman and Heinz, 2011), as consonant sound often has shared partials and more regular harmonic patterns. The clearer periodic peaks produced by consonant sounds enables us to detect the pitch of the tones more easily. In the case of dissonant tones, neuronal firing occurs in more irregular patterns, making for a more ambiguous cue for pitch detection. Our auditory mechanisms are able to process simpler and clearer periodic information of sound more quickly and effectively.

2.2.6. Neural correlates

Neurophysiological studies that record neural responses to stimuli elicited at various levels, such as at the level of the auditory nerve, brain stem, and auditory cortex, provide rich evidence on how the brain processes and perceives harmonic relationships between different pitches. One of the key findings of neurophysiological studies is that brain responses differentiate consonance and dissonance even at the pre-attentive, peripheral level, which might provide some indication of the innateness of C/D perception.

Tramo et al. (2001) reveal neural correlates of C/D by recording and analysing how the auditory fibres of cats respond to intervals, and by showing how the autocorrelation histograms of neural responses that these cats produce finely mirror the patterns of the sound waves of those intervals. The histograms showed a more regular pattern of neuron firing when the cats were played a perfect fifth then when played a minor second—intervals that, by convention, are considered consonant and dissonant respectively. Bidelman and Heinz (2011) demonstrated that the perceptual rank order of the C/D of intervals and chords can be predicted from the patterns of firing of peripheral neurons in a person's auditory nerves. An autocorrelation function of auditory nerve activity shows more regular and periodic distribution in response to more consonant intervals and chords than is the case with dissonant ones. Further, consonant intervals had a higher neural pitch salience, while dissonant intervals had a lower neural pitch salience, indicating that our auditory nerve activity mirrors our perceptual judgements of the C/D of intervals.

Neural correlates of C/D perception have also been found in the brainstem and auditory cortex. In a pair of studies by Bidelman and Krishnan (2009, 2011), a recording of the frequency-following responses (FFR) elicited by nine dyads revealed that consonant intervals generated more neural activity in the brainstem than dissonant intervals. Itoh et al. (2010) recorded the time-course of neuroelectric activity generated in the cerebral cortex using scalp-recorded event-related potentials (ERPs). They found that the responses elicited by the stimuli clearly differed according to which interval was heard, and responses to consonant and dissonant intervals reflected the categorisation of C/D according to music theory. Fishman et al. (2001) demonstrated that the magnitude of oscillatory phase-locked activity in the primary auditory cortex as evoked by chords correlated with the degree of perceived roughness of these same chords. Also, neural responses to dissonant chords in the primary auditory cortex were phase-locked to the difference frequency, while consonant chords did not prompt much phase-locked activity (Fishman et al., 2001).

Neuroscientific studies have also demonstrated that consonant and dissonant chords activate different regions of the brain to different extents, as can be seen from the findings of Minati, Rosazza, D'Incerti, Pietrocini, Valentini, Scaioli, Loveday, and Bruzzone, (2009). Using functional magnetic resonance imaging (fMRI) and ERPs, they were able to reveal that consonant chords activated certain regions more strongly—predominantly, regions in the right hemisphere, such as the inferior and middle frontal gyri, the lateral premotor cortex, and the inferior parietal lobule. Regions that were activated by dissonance, meanwhile, were spread over the left hemisphere. Fishman et al. (2001) likewise found evidence of different neural responses in different regions of the auditory cortex: phase-locked activities were evoked by dissonant chords in Heschl's gyrus, while no significant phase-locked activity was found in the planum temporate. These examples show that our brains are able to distinguish between consonance and dissonance, and that the perception of consonance and dissonance are different phenomena.

2.3. The innateness of C/D

2.3.1. Brain lesions and impaired hearing

Data gathered from studies of people with amusia and impaired hearing demonstrate that our perception is mediated and constrained by the functioning of the auditory system and brain. Peretz, Blood, Penhume, and Zatorre (2001) reported that a woman who had suffered from music perception and memory disorder due to bilateral lesions to the auditory cortex could not discriminate between different levels of pleasantness in consonant musical excerpts, which people without bilateral lesions were able to do. She could still tell the difference between major and minor modes, and happy and sad music, but she could not manage C/D discrimination. The woman had suffered damage to regions of her brain known as the superior temporal gyri, which deal with the perceptual processing of musical input. This damage thus made it difficult for her to judge the consonance or dissonance of sounds.

People with cochlear hearing loss generally have greater difficulty in detecting pitch and in discriminating between different frequencies than those with normal hearing. This is because their auditory filters are broader than normal, and this reduces frequency selectivity (Moore & Carlyon, 2005). Frequency selectivity refers to 'the ability of the auditory system to separate out the frequency components of complex sounds' (Plack, 2004). In other words, two tones whose frequencies are close might often be categorised in the same filter by people with cochlear hearing loss, and consequently the difference in pitch between the two notes are not detected. In addition, phase locking is less precise for people with cochlear hearing loss, and 'the propagation time of the travelling wave along the basilar membrane and the relative phase of the response at a different place may differ from normal' (Moore & Carlyon, 2010). In terms of C/D perception, Tufts, Molis, and Leek (2005) reported that people with sensorineural hearing loss did not discriminate between the C/D levels of intervals as clearly and finely as did people with normal hearing, and that this lack of discrimination is due to the compression of pitch in the impaired auditory system. They also discovered that dissonance perception is related to frequency selectivity. The auditory filter bandwidth for participants with sensorineural hearing loss was significantly wider than it was for people with normal hearing, meaning that people with normal hearing are much better at distinguishing between two notes of different frequencies. Due to their wider frequency selectivity it is more difficult for people with hearing loss to discriminate between small differences in pitch, and consequently it is more difficult for them to make C/D judgements.

2.3.2. Babies and consonance

Studies employing babies have provided some researchers with further grounds for considering that the perception of C/D is innate rather than the result of enculturation. Several studies have demonstrated that babies, who have not had much exposure to music and have therefore have not acquired a musical schema, nonetheless prefer consonance over dissonance. These infant studies employed babies as young as four months old, and measured their preference for consonance by noting the length of time they looked at a screen or an experimenter, or the length of time they stayed still without moving around while the stimuli were presented (Trainor Tsang, & Cheung, 2002; Trainor & Heinmiller, 1998; Plantinga & Trehub, 2014; Zentner & Kagan, 1998). In most studies, babies tended to look longer when played consonant stimuli than they did for dissonant ones (Trainor et al., 2002; Trainor & Heinmiller, 1998; Zentner & Kagan, 1998), and moved less when consonant stimuli were presented than when dissonant ones were (Zentner & Kagan, 1998). These results are normally interpreted as an indicator of infants' innate preference for consonance.

However, Plantinga and Trehub (2014) objected that looking time is not sufficient as an indicator because it is not possible to infer merely from the length of time that babies look whether they are making any explicit aesthetic judgement. They urged that we need other behavioural or physiological measures to provide solid evidence for babies' innate preference for consonance. In any case, babies have already been exposed to sound and music since they were in their mother's womb, so there is a possibility that they have already learned how to interpret sound information and music in their environment (Trainor et al., 2002). While these studies on infants provide interesting perspectives on the perception of C/D that cannot be gleaned from studies employing adults as participants, they are not strong enough to provide irrefutable evidence for the biological origins of C/D perception.

2.4.Musical C/D

As we have seen, psychophysical and neuroscientific studies help to reveal the theory behind C/D, and help us to understand the process of C/D perception. These studies show how the physical acoustic features of sounds and our auditory systems shape the perception of sensory C/D, which in turn prove that sensory C/D perception as an intrinsic ability of human beings. However, it should be remembered that, in our everyday experience of music, we listen to chords and intervals within the flow of an entire piece. Our C/D judgement of a chord when heard in a piece of music is determined not only by its acoustic features, but also by factors such as the musical context in which it appears (Gardner & Pickford, 1943; Lundin, 1947), its harmonic function, and the listener's level of familiarity and musical schema based on the principles of harmonic progression and chord usage. These are all factors that are learnt and acquired through exposure to the music of particular cultures and genres.

2.4.1. Musical schema

A schema is a mental structure or system of organising and perceiving information and events in the external world. According to Krumhansl and Castellano (1983), a musical schema is the subset of knowledge about regularities underlying music that 'interacts dynamically with [the listener's] sensory-perceptual information' (p. 325). A musical schema is acquired through exposure to music in a particular style or culture since birth, and thus represents a storehouse of musical experience for the listener, governing the way in which they perceive music. A musical schema results from 'our ability to perceive, remember, conceptualise, and act on musical information [so that we can] reproduce more complex musical knowledge' (Dowling & Harwood, 1985). The listener's musical experience forms a musical schema, which will provide the foundation for processing new musical information, and new musical information will in turn alter the listener's musical schema. As such, a musical schema is a flexible and adjustable framework.

Lundin (1947) asserts that there is no such thing as absolute consonance or dissonance. This assertion gains support not only from the fact that there is still a lack of consensus about how these terms should be defined, but also from the fact that definitions of C/D have changed throughout the history of Western music. The major sixth was thought to be dissonant until the 13th and 14th centuries, although it is unlikely to sound dissonant to modern ears. Modern listeners who are familiar with Western (serious) music after tonality had lost its authority may be more tolerant towards Wagner's Tristan than its original 19th century audience, who found the then new chromatic and tritone-laden sound shocking and unpleasant (Nattiez, 1990). It may in part be musical schemata that account for this difference in listeners' perceptions of C/D. The difference between the musician's and the non-musician's perception of C/D – a topic that will be discussed in more depth later - may partly derive from the variety of musical schemata, schemata that have been shaped by individual musical experiences and training. It is thought that musical schemata are plastic and elastic, so one's schema changes in the course of musical life according to the musical experience built up by the individual. Consequently, repeated exposure to erstwhile dissonant chords will enable the listener to re-mould his musical schema, perhaps allowing him to perceive the dissonant chord more positively.

2.4.2. Familiarity

It is known that familiarity due to repeated exposure influences one's perception of and responses to stimuli. People tend to have more positive responses to stimuli with which they are familiar, a phenomenon known as 'mere repeated exposure effect' (Zajonc, 1968: 2001). Some studies demonstrate that repetition and familiarity have the effect of increasing positive appreciation for a wide range of stimuli, such as tones, intervals, semitones, music made from quarter-tones (Meyer, 1903), unfamiliar musical genres (Krugman, 1943), pieces of Hindemith and Schoenberg (Mull, 1957), Pakistani music (Heingartner & Hall, 1974), and 'patchwork compositions', which are created from the combination of excerpts of three notably different pieces of music (Tan, Spackman, & Peaslee, 2006). In terms of C/D, chords sound more consonant when heard in a "traditional" harmonic progression as opposed to a "non-traditional" one (Roberts, 1986). The influence of context on the evaluation of dissonance was also observed in an experiment by Johnson-Laird et al., (2012), in which major triads, sevenths, minor sevenths, and minor triads were judged to be more consonant when heard in the context of a common harmonic progression than when in random, non-tonal sequences.

2.4.3. Expectation

Expectation refers to the ability to predict upcoming musical events in a piece of music (Bharucha, 1994; Huron, 2006; Justus & Bharucha, 2001; Meyer, 1952). According to Meyer (1956), expectation derives from both 'the nature of human mental processes … of the data presented by the senses', and from 'learning', although in actual perception these two will interact each other. In the course of shaping one's musical schema, repeated exposure to a stimulus increases familiarity, and this familiarity then forms the basis for what one expects in the future. Familiarity and expectation appear to be similar concepts, since both of them develop from the listener's musical schema. However, they differ in two important ways: familiarity forms the foundation for the listener's expectations, while expectation (in contrast to familiarity) is liable to induce emotion depending on the outcome. According to Huron (2006), an expected outcome can induce positive responses, such as satisfaction or joy, whereas an unexpected outcome can cause negative emotional responses. However, that is not always the case: a very predictable outcome could induce boredom, while an unexpected outcome may turn out to be a nice surprise. Expectation is a key factor in inducing emotion in the listener, but what kind of emotion is induced will depend on the balance between expectation and outcome.

2.4.4. Tonal hierarchy

The notion of tonal hierarchy is one of the dominating principles that governs the structure of Western music and that helps to explain the formation of the listener's musical schema and expectations. According to Krumhansl and Cuddy (2010), there are two principles on which tonal hierarchy relies, and these are: ‘cognitive reference points’ and ‘sensitivity to statistical regularities’. A cognitive reference point is a cue to enable perceptual objects to be ‘encoded, described, and memorised’ (p. 53), which helps the listener to process musical information. The other principle, sensitivity to statistical regularities, concerns the learning of regularities of language and music based on the frequency of their occurrence. More frequently occurring objects are learned, encoded, and memorised as more important than less frequently occurring ones.

Within Western tonal music, there are twelve possible tones and seven possible diatonic chords in a scale. These seven possible diatonic chords can be constructed on any degree of a diatonic scale, from the tonic to the leading tone chord (Benward & Saker, 2002). However, musical pieces typically do not consist of equal numbers of every tone or chord; rather, certain tones and chords can be expected to appear more often than others. Tones or chords that appear more frequently, and at more important musical moments, tend to be recognised as important references that provide the listener with ‘a framework for encoding and remembering the sounded tones’ (Krumhansl, 2000. p. 463). The tonic tone and chord commonly appear more frequently than other tones and chords, since the tonic helps to establish a sense of key by opening and ending the musical sequence, and it thus functions as a ‘reference’ (Krumhansl, 1990; Krumhansl & Cuddy, 2010). Dominant and subdominant chords also occur frequently, and each plays an important role in helping to shape the harmonic flow of the music, since their appearance tends to precede a move to the tonic and to the dominant, respectively. Tonic (I), dominant (V), and subdominant chords (II/IV) are called ‘primary chords’, as together these comprise the fundamental elements of tonal music. The other diatonic and non-diatonic chords follow these primary chords, and it is this that creates the order of the tonal hierarchy.

Adherents to the psychological approach have meticulously studied this tonal hierarchy of tones and chords. A series of studies by Krumhansl and her colleagues have on several occasions tested the structure of the tonal hierarchy by using the probe tone technique, which asks listeners to judge how well a target stimulus fits with an initial stimulus (priming) on a 7-point scale. For example, Krumhansl and Shepard (1979) presented participants with an incomplete ascending and descending C major scale (C-D-E-F-G-A-B, or C-B-A-G-F-E-D), followed by each of the 12 tones of the scale. Listeners were asked to rate how well each of the 12 tones of the C major scale fitted with the preceding scale. The results show that C was rated most highly, as it is the tonic and most proximate in pitch, while G, the dominant, and E, the median, were also highly rated (Krumhansl & Cuddy, 2010; Krumhansl & Shepard, 1979). A further study by Krumhansl and Kessler (1982) used various stimuli, such as scales, chords, and short and long chord sequences as preceding stimuli, and produced similar results to Krumhansl and Shepard (1979) and Krumhansl (1979). The standardised listener ratings on the well-fittingness of judgements for both major and minor were known as the *K-K profile*, which has been used by subsequent studies (Thompson & Parncutt, 1997) to develop theories about the influence of the tonal hierarchy on the listener's perception of chords. A series of studies by Krumhansl and her colleagues (Krumhansl, 1979; Krumhansl & Kessler, 1982; Krumhansl & Shepard, 1979; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982) using probe tone techniques produced consistent results. Listeners perceived the tonic tone and chord featuring in the prime stimulus as being most fitted to the tonic, followed by the dominant and subdominant tone and chord, other remaining diatonic tones and chords, and finally non-diatonic tones and chords. These results indicate that listeners' perceptual judgements of the tonal hierarchy are consistent with the principles of music theory.

2.4.5. Harmonic context and expectation

The tonal hierarchy creates the structure of music, the harmonic progression that underlies music and keeps it moving forward. The harmonic progression of a piece of music is in turn created by the combination of chords with different harmonic functions, and in it we hear the constant flow of shifting tones and more or less stable elements. For instance, music commonly starts with the tonic and, from there, moves to the subdominant or dominant. Each harmonic function attracts other functions of varying stability - so for example the subdominant induces the dominant, while the dominant attracts the tonic like iron filings to a magnet. Each harmonic progression invariably starts and ends with the tonic, but, in the course of its movement, the harmonic functions change from stable to unstable and back again, resulting in '[asymmetrical] properties of relationship between tones and/or chords' (Krumhansl, 1979). However, the tonal hierarchy and a piece's harmonic progression do not depend on the sonority of each individual tone or chord so much as on the overall context, on the relationship between all tones and chords. The fixed pitch of an individual tone or chord does not function as an absolute cognitive reference point in music (Krumhansl & Cuddy, 2010), since the tonal hierarchy is determined in relation to other tones and chords differing in tonal importance and stability (Tillmann, 2008). A tone of C is the tonic when heard in the key of C major, but it is the dominant when heard in the key of F major, and the mediant in the key of A minor. Likewise, the triad C-E-G changes its function depending on which key it is heard in.

The listener implicitly learns to acquire a sense of tonal hierarchy that is determined by the relative importance and stability of tones and chords, and the principles of harmonic progression are established through repeated exposure to combinations of chords of differing tonal importance and stability. Knowledge of the rules of harmonic progression will be stored in his or her musical schema, and commonly occurring harmonic progressions will form the basis of their harmonic expectations. One method of investigating these harmonic expectations based on the tonal hierarchy is to test how expectations about upcoming events influence the processing of those events (the targets), and to measure the accuracy and speed with which participants anticipate them, or to measure participants' brain responses to target stimuli. This method assumes that the listener will be most likely to expect music to be governed by the principles of Western tonal hierarchy. By manipulating the target stimuli while keeping preceding events (priming) the same, it should be possible to note the effect of expectation as generated by priming on the listener's perception of the target stimuli. Participants are often asked to judge whether the target stimuli (often a chord, or a two-chord sequence) is in-tune or out-of-tune, whether they have a sense of a phrase's being complete, and to what extent the chords heard 'belong'.

A study by Bigand and Pineau (1997) tested the effects of global context on musical expectation, employing sequences consisting of eight chords as musical stimuli. All sequences ended on an acoustically identical chord, but this chord differed in harmonic function since the sequences were in different keys and involved different chord progressions. Sequences ending with V-I chords were expected, whereas those ending with I-IV chords were unexpected. Half of the final chords were consonant while the other half were dissonant, with the pitch of the fifth increased by a semitone. Participants were asked to judge: whether the last chord was consonant or dissonant; whether the phrase had a sense of completion; and whether there was a feeling of belongingness to the final chord. It was found that sequences with expected endings were processed faster and—regardless of whether they were consonant or dissonant—were judged more accurately than those that were unexpected. This result suggests that an acoustically identical chord can be perceived differently depending on its harmonic function, and the study itself highlights the importance of context over and above the sonority of chords when it comes to the listener's processing of musical information.

The same experimental method was adopted in a study by Bigand, Madurell, Tillmann and Pineau (1999), but on this occasion the three levels of expectation were set as follows: high-expected, middle-expected, and unexpected. Here again, final chords performing an expected harmonic function—that is, chords in an authentic progression resolved by a V-I cadence—were judged more quickly and correctly than middle-expected and unexpected ones. Other studies (Tillmann, Janata, Birk, & Bharucha, 2008; Tillmann & Lebrun-Guillaud, 2006; Tillmann & Marmel, 2013) employing the same methods produced similar results. The most expected target stimuli, such as the tonic tone or chord to close the sequence, were processed faster and judged more accurately than those that were unexpected, such as dominant or subdominant chords.

Studies that measure physiological and brain responses also provide evidence for the influence of expectation on the processing of harmony, and for the importance of context. Regnault, Bigand, and Besson (2001) extended Bigand and Pineau's (1997) study by examining listeners' event-related brain potential. Dissonant chords at the end of sequences—which were harmonically unrelated and therefore unexpected—triggered a larger late positive component than harmonically related consonant chords. A late positive component is likely to be elicited when unrelated or incongruent stimuli are presented, and it is therefore considered an electrophysiological indicator of expectancy. The difference in the amplitude of response between the least expected subdominant chords and the most expected tonic chords indicates that listeners – both musicians and non-musicians - were sensitive enough to detect contextual changes in the harmony of the sequences.

Previous studies have reported listeners' sensitivity to harmonic functions, finding that the Neapolitan sixth chord in an unexpected position within a harmonic progression elicits a greater amount of negative brain activity than when it occurrs on the subdominant as is common practice (Koelsch, Gunter, Friederici, & Schroeger 2000; Loui, Grent-'t-Jong, Torpey, & Woldorff, 2005; Maess, Koelsch, Gunter, & Friederici, 2001). Otsuka et al. (2008) also demonstrated that listeners perceived an acoustically identical chord as more stable when it was on the tonic (I) than when it was on the submediant (VI), and that chords on the submediant elicited larger N1m in Magnetoencephalography (MEG) than when the same chord was on the tonic.

Steinbeis, Koelsch, and Sloboda (2006), and Koelsch, Kilches, Steinbeis, and Schelinski (2008) measured physiological activity and brain responses to musical excerpts with several different endings: very unexpected, unexpected, and expected. The very unexpected versions triggered the strongest skin conductance responses and the largest brain responses, such as early right anterior negativity (ERAN) and N5, reflecting the fact that there is emotion inducing and cognitive processing going on, respectively. Unexpected harmonies and chords induced an emotional response, and the intensity of this response increased in line with the increase in the level of unexpectedness. A study by Brattico, Jacobsen, De Baene, Glerean, and Tervaniemi (2010) also demonstrated that different levels of harmonic congruency between the final chord of a sequence and the previous chords (congruent, ambiguous, and incongruent) elicited different ERP responses. Listeners were presented with the same sequence twice and were given two different tasks: on one occasion they were to judge whether they liked or disliked the chord sequence (affective task), and on another occasion they were to judge whether the last chord was correct or incorrect (cognitive task). The ERP negative deflection differed according to the congruency of the final chord. Harmonically correct final chords elicited a larger positive response than harmonically incorrect ones. The study also found that, despite the fact that the same stimulus chord sequence was played for both affective and cognitive tasks, different ERP responses were elicited in each case. The affective task elicited a late positive potential, while the cognitive task elicited a large negative response. These examples all go to show that it is not merely the acoustic features of a chord that influences the listener's response to chords, but also expectation and harmonic context.

2.5. Pleasantness, Stability, and Tension

2.5.1. Pleasantness

Another important issue concerning C/D is its relationship with pleasantness. It is a relatively common notion that a chord's being consonant is equivalent to its being pleasant, while dissonance is considered unpleasant (Tenney, 1988). A study by van de Geer Levelt, and Plomp (1962) that used semantic differentials found that the notions of consonance, beauty and euphony occupy the same dimension in semantic space, indicating that consonant sound tends to be evaluated as aesthetically pleasing. A study by Blood, Zatorre, Bermudez, and Evans (1999) reported a positive correlation between the dissonance level of a musical stimulus and listener ratings of unpleasantness as well as dissonance. This congruency between consonance and pleasantness on one hand, and dissonance and unpleasantness on the other, may have a neurophysiological basis. Koelsch et al. (2006) found that consonance and dissonance activate brain regions that are related to emotional processes by recording neural responses to consonant musical excerpts and then manipulating these excerpts to make them sound dissonant. At the presentation of dissonant stimuli, activations were observed in the amygdala, which is activated when negative emotions are generated, and in three other regions connected with the amygdala, while consonant music decreased activation in these regions.

Due to this congruency between consonance and pleasantness, it is not uncommon for studies on the perception of C/D to use a 'pleasant/unpleasant' metric to evaluate listeners'

C/D perceptions of chords in place of a 'consonant/dissonant' metric (Cook & Fujisawa, 2006; Johnson-Laird et al., 2012; McDermott et al., 2010). However, it may not be the case that consonance is always perceived as pleasant, as there may be individual differences between perceptions of C/D and P/U. Differences between perceptions of C/D and P/U have been highlighted in a study by Guernsey (1928). In her study, musically trained participants judged intervals with the highest levels of fusion and smoothness, such as octaves and perfect fifths, among the least pleasant.

2.5.2. Stability

Just as consonant chords are often assumed to be pleasant, so are they often assumed to be stable and relaxed. Meyer (1967) wrote that the perception of stability and tension is necessary for the understanding and enjoyment of music. Stability is a concept that indicates the relative importance of each tone in a scale, and which establishes the tonal hierarchy (Bharucha, 1994; Bigand, 1997; Krumhansl, 1990). In a given scale, diatonic tones are more stable than non-diatonic tones, and among all chord functions the tonic is the most important and stable, followed by the dominant and subdominant (Bharucha, 1994). What determines the stability and importance of a tone or chord is the frequency of its occurrence. Frequently occurring tones and chords are perceived as more stable and important, because of their role as cognitive cues in helping the listener establish a sense of key (Bigand, 1997: Krumhansl & Cuddy, 2010). The concepts of stability and musical tension are similar in that musical events that are stable and lacking in tension tend to be heard as consonant, and vice versa (Bharucha, 1994), and in that it is the continuous movement of events, from stable/relaxed to unstable/tense, that creates the flow and dynamics of music (Lerdahl & Jackendoff, 1983; Mayer, 1956). Further, empirical studies have shown that judgements of consonance and dissonance are often coincident, respectively, with judgements of stability and instability, and relaxation and tension (Bigand & Parncutt, 1997; Bigand, Parncutt, & Lerdahl, 1996). The perception of stability is attributable to our knowledge of the tonal hierarchy and to the acoustic features of stimuli, as will be outlined later.

2.5.3. Tension

Lerdahl (1996, 2001) modelled tonal tension by quantifying hierarchical event structure, tonal pitch space, surface dissonance, and melodic attractions. On this model, tonal tension depends on: tonal hierarchy (the more stable a function is, the more relaxed the musical event will be); the distance between preceding and following chords within the tonal pitch space (e.g. chromatically, diatonically, and in terms of the cycle of fifths); surface dissonance as determined by the scale degree of chords; the number of non-harmonic tones in each chord; the intervallic structure of each chord; the metric position of each chord; and melodic attraction, which is the strength a pitch has to anticipate the following pitch (e.g. the leading tone makes the listener expect the tonic). This model is generally well supported by empirical evidence (Bigand et al., 1996; Bigand & Parncutt, 1999; Toiviainen & Krumhansl, 2003; Lerdahl & Krumhansl, 2007), with the exception of the melodic attraction variable, which was less successful as a predictor (Lerdahl & Krumhansl, 2007).

Margulis (2005) posits three types of tension; surprise-tension, denial-tension, and expectancy-tension. Surprise-tension occurs when an unexpected event happens, and is low when the outcome event is very predictable. The violation of expectation, or the deviation of musical events from the listener's musical schema, is regarded as a major cause of musical tension (Krumhansl, 1996). Steinbeis et al. (2008) found that unexpected chords at the end of musical excerpts generate more tension than expected chords, as indicated by the increase in the amplitude of participants' electrodermal activity and early negativities when exposed to greater unexpectedness. The second tension, denial-tension, is that which occurs when the outcome event frustrates the listener's expectations. Denial-tension is a function of the difference between the expected event and the actual realised event. The last form of tension, expectancy-tension, occurs when the music exhibits a strong urge to move to next event (Margulis, 2005). In other words, it occurs when certain musical events trigger an expectation for future musical events. In addition to the dominant function as mentioned above, dissonance may be another cause of this expectancy-tension, as Meyer (1956) explains that 'a dissonant interval causes a restless expectation of resolution, or movement to a consonant interval' (p. 228).

According to Western tonal music theory, a dissonant chord normally resolves onto a consonant chord, and that is what the listener who has developed their musical schema from listening to tonal music will expect. Dissonant chords (as defined by music theory) are thought to be unstable due to the ambiguity of their chord function, and so require resolution onto a consonant chord with a more stable function. Due to its acoustic features and unstable function, a dissonant chord generates two expectations: an expectation of its being resolved by a following consonant chord, and an expectation that the musical tension triggered by the dissonance will be released when this resolution occurs. The listener expects this dissonance to be resolved and the tension released. This need for dissonance to be resolved is experienced as a musical tensing–relaxing relationship, which is one of the most fundamental elements of Western tonal music (Lerdahl, 1996, 2001; Lerdahl & Jackendoff, 1983).

The confirmation or violation of expectations that tension creates may also induce emotion in the listener (Meyer, 1956; Huron, 2006). According to Juslin and Västfjäll (2008), 'musical expectancy' is one of six psychological mechanisms that underlie the listener's emotional response to music, and emotions such as surprise, disappointment, and pleasure are triggered when the listener's expectations are delayed, violated or satisfied. The listener will experience positive emotions when musical events conform to what he had expected, while negative emotions will be evoked when the outcome differs from what was anticipated

(Huron, 2006). So, it can be speculated that when a consonant chord follows a dissonant chord and thus resolves the dissonance and releases tension, expectations will be fulfilled, and positive affects, such as pleasure, will be induced.

On the other hand, an unexpected outcome might also play an important role in inducing *pleasure*. Great amounts of pleasure can be triggered from the appearance and sustaining of an unexpected chord that is subsequently resolved. A large discrepancy between expectation and outcome induces emotions, a phenomenon that is called ‘contrastive valance’ (Huron, 2006). The pleasure resulting from the satisfaction of expectations will be greater if that dissonant chord was in some way unexpected (perhaps its occurrence was very unusual, or it was very dissonant, or its duration was unexpectedly long). This contrast between unexpected dissonance and expected consonance results in greater pleasure as Meyer (1956), referring to Zarlino’s view on the role of dissonance, proclaims: “dissonance adds beauty and elegance to the work and makes the consonance which follows more acceptable and sweet” (Meyer, 1956. p. 229). However, if the dissonant chord is not resolved and the music remains dissonant, expectations will be violated rather than satisfied. Consequently, negative emotions such as frustration or increased tension are likely to occur.

2.5.4. The perception of stability and tension

There are similarities between the perception of stability/instability and tension/relaxation on the one hand, and the perception of C/D on the other, in that they are both influenced by acoustic features and by tonal hierarchy. Sensory dissonance, and in particular roughness, has a large influence on the perception of instability and tension (Lerdahl & Krumhansl, 2007). Instrumental sounds with roughness trigger tension (Pressnitzer, McAdams, Winsberg, & Fineberg, 2000); and chords with more roughness are perceived as tenser when in a harmonic context (Bigand, Parncutt & Lerdahl, 1996), and as more unstable even in atonal music

(Dibben, 1997). However, Pressnitzer et al. (2000) found that rough sounds do not always go hand in hand with perceptions of tension, suggesting that there may be other acoustic features besides roughness that influence the perception of tension. For instance, Paraskeva and McAdams (1997) found that the same musical excerpt can trigger differing degrees of tension depending on timbre - excerpts played on piano were perceived as more tense than orchestral versions of the same music, which was attributed to the piano's "sharp attack". In addition to sensory roughness and dissonance, dynamics is another discussed feature of musical tension. Empirical studies report that the louder a piece of music is, the more tension listeners will experience (Burnsed & Sochinski, 2001; Farbood, 2012; Farbood & Upham, 2013; Granot & Eitan, 2011; Ilie & Thompson, 2006; Krumhansl, 1996). Pitch height and register, and tempo are other factors that have an influence on perceived tension: music with a higher pitch and a faster tempo will typically trigger more tension than music with a lower pitch and a slower tempo (Ilie & Thompson, 2006: Granot & Eitan, 2011: Farbood, 2012), although extreme low registers can also trigger tension (Granot & Eitan. 2011). Granot and Eitan (2011) found some complicated interactions between these different factors. For example, whether a rising pitch will induce more tension than a falling pitch depends to an extent on pitch register and dynamics, and the effect of tempo likewise depends on dynamics.

Additionally, the perception of stability and tension is partly attributable to the tonal hierarchy of chords and to listener expectations as shaped by their musical schema. Listeners perceive more important tones in the musical hierarchy as more stable (Bigand, 1997). This relationship between stability and tonal hierarchy has been explored in various empirical studies. For example, it has been found that the most stable ending to a cadence, a resolution to the tonic, will elicit the greatest sense of completion in most listeners (Tillman and Lebrun-Guillaud, 2006); and that tones with greater stability are processed more accurately and quickly than less stable tones (Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003;

Bigand, Tillmann, Poulin-Charronnat, & Manderlier, 2005; Tillmann, & Marmel, 2013). As for tension, more important tones in the tonal hierarchy tend to be heard as less tense (Bigand, Parncutt & Lerdahl, 1996), and chords that perform expected harmonic functions are perceived as being less tense, while chords that perform unexpected harmonic functions induce tension (Steinbeis et al., 2006). Through the use of the continuous rating method, which records the listener's real-time tension responses while listening to musical stimuli by having them slide a computer bar, studies reveal that prominent tension peaks tend to occur at points at which the dominant function features, and this tension dissipates as the dominant function resolves into the following tonic (Toiviainen & Krumhansl, 2003; Lehne, Rohrmeier, Gollmann, & Koelsch, 2013).

2.6. C/D as a learned phenomenon

2.6.1. Musical experience and plasticity

In support of the thesis that C/D perception is to a large extent down to nurture, it appears that there are differences between people with musical training (musicians) and people without musical training (non-musicians), despite the fact that we share the same basic brain structure and auditory system. Many studies report that musical training and experience increases sensitivity to sensory C/D (Bidelman, 2013; Brattico, Pallesen, Varyagina, Bailey, Anourova, Järvenpää, Eerola, & Tervaniemi, 2009; Itoh, Suwazono, & Nakada, 2010; Roberts, 1986; Rogers, 2010; Schön, Regnault, Ystad, & Besson, 2005). Musicians are generally better able to identify dissonance (Brattico et al., 2009), and to discriminate between the perfect consonance, imperfect consonance, and dissonance of dyads more clearly than non-musicians (Schön et al., 2005). Furthermore, musicians rely to a greater extent on their understanding of harmonicity than on roughness when judging C/D (Kung, Hsieh, Liou, Lin, Shaw, & Liang, 2014; McDermott et al., 2010). Musical training is likely to enhance this sensitivity and preference for harmonic intervals and chords, though both musicians and non-musicians have the same aversion to roughness (Cousineau et al., 2012; McDermott et al., 2010).

Musicians' sensitivity to C/D has also been revealed in the Electroencephalography (EEG) data collected from a study by Itoh et al. (2010). In musicians, the amplitude of N2 of the auditory evoked potentials elicited large negativity when intervals normally considered as dissonant were presented, and the amplitude of N2 increased with greater sensory dissonance. Musicians are also able to discern different tunings such as just intonation and Pythagorean from equally-tempered (Roberts, 1986); while at the neural level, the mismatch negativity brain response (which is a brain response evoked by a stimuli that does not frequently occur or that deviates from the standard) showed that musicians were able to discriminate between mistuned and dissonant chords more accurately than non-musicians (Brattico et al., 2009). Other studies examining listeners' brain activities provide evidence of there being some difference between the perception of musicians and non-musicians. For example, differences between musicians' C/D judgements of intervals and those of non-musicians were observed in data on ERPs (Schön et al., 2005); musical experience was found to enhance representations of the harmonicity of consonant chords in the FFR (Bones et al., 2014); consonant and dissonant sounds were found to activate different regions of the brains of musicians and non-musicians (Minati et al., 2009); and musicians' brainstem responses to dissonant intervals were found to be more robust and coherent than those of non-musicians (Lee, Skoe, Kraus, & Ashley, 2009).

An extensive musical training seems to make listeners more sensitive not only to the sonority but also to the harmonic structure of Western tonal music. Schellenberg and Trehub (1994) established that listeners with more extensive musical training relied more on the prevalence of intervals in Western music than on the mere simplicity of the frequency ratios of two tones when judging the pleasantness of intervals. Listeners with more extensive musical training perceived intervals with simple frequency ratios, such as the major third or the major sixth, as more pleasant than intervals with even simpler frequency ratios, such as the octave or the perfect fifth (Malmberg, 1918; van de Geer, Levelt, & Plomp, 1962). According to Schellenberg and Trehub (1994), this may be explained by the fact that the major third and the major sixth are more common in Western music than either the octave or the perfect fifth, and that therefore the judgements of musically trained listeners were influenced by their familiarity with these intervals. However, some aspects of chord perception seem to be less susceptible to the influence of extensive musical training. In terms of judgements of the aesthetic qualities of chords such as pleasantness, musical training was found to have 'no reliable effect' on the pleasantness ratings of chords in isolation (Johnson-Laird et al., 2012), or in context (Roberts, 1986). Also, musicians' judgements of the semantic connotations of the C/D of intervals were not dissimilar from those of non-musicians (Costa, Bitti, & Bonfiglioli, 2000).

In terms of the perception of stability, there is no evidence to indicate that musical training has any influence on such perceptions. Bharucha and Krumhansl (1983) studied hierarchies of the harmonic stability of chords; but they averaged their experimental data across all participants for analysis after finding no difference between musicians and non-musicians. Similarly, Bigand (1997) did not find any apparent difference between musicians' and non-musicians' perceptions of stability in melodic sequences, concluding: "the explicit learning of music may not be necessary to perceive subtle structures in tonal musical sequences". However, Bigand et al. (1997) did uncover some influence from musical training in their participants' perceptions of tension. Musically trained listeners' tension ratings were positively correlated with the roughness of chords, and negatively correlated with pitch distance and the tonal stability of chords. The effect of chord type and mode were clearly observed in musicians, whose tension ratings for minor chords and seventh chords were significantly higher than for major chords. Lahdelma and Eerola (2014) likewise found that musically trained listeners tended to give higher ratings for augmented triads than less musical listeners did. Taken together, these results suggest that musical training enhances sensitivity to the acoustic features of chords (such as harmonicity, roughness, and the frequency relationships between a chord's constituent tones) as well as to tonal hierarchy.

2.6.2. Enculturation

Another factor in favour of seeing C/D perception as a product of learning and experience is the manifest cultural differences in C/D perception. In Western tonal music, there is an assumption that 'rough sounds are inherently bad and unpleasant' (Vassilakis, 2005). Dissonance is associated with negative words (Costa et al., 2000; Sollberger, Reber, & Eckstein, 2003), and induces negative emotions and physiological responses that support this labelling (Dellacherie, Roy, Hugueville, Peretz, & Samson, 2010). Beating, one of the causes of dissonance, is normally avoided. However, some musical cultures appreciate dissonance and beating, and encourage their appearance. For instance, some instruments such as a sitar and shamisen, a Japanese traditional instrument with three strings, are intentionally structured to create a buzzing noise by having their strings touch the nut of the instrument (Malm, 2000). Another example is Balinese gamelan, in which the instruments are tuned in order to create beating when they play together. In Bosnia-Herzegovina and Dalmethian Zagora of the Balkan, meanwhile, a chorus alternatively follows and accompanies a solo singing section, singing the same melody a major or minor second apart. This style of performance is called *ganga,* and people in the region consider the intervals 'pleasant and desirable' (Vassilakis, 2005. p.127), although people from outside of the region are more likely not to appreciate the resulting sound (Vassilakis, 2005).

Butler and Daston (1969) compared the C/D perception of American and Japanese students. Both groups of participants had a task to discriminate different intervals and afterwards ranked twelve intervals by preference. Regardless of the discrimination ability of individuals, the rank ordering of intervals remained consistent, and there was no significant difference between the two cultural groups. This is not a surprising result as Japanese people at that time had already had sufficient exposure to Western tonal music to have a musical schema akin to that of their American counterparts. Western tonal music dominated musical culture in Japan from the early twentieth-century, and the 1960s—the decade in which this study was published—was the era of Rock 'n' Roll, when Japanese young people were listening to Elvis Presley and The Beatles.

On the other hand, a study by Maher (1976) reveals cultural differences in the perception of intervals between Indian and Canadian listeners. The two cultural groups had to give twelve intervals 'restful' or 'restless' ratings, and the ratings they gave were significantly different. Indian participants generally rated intervals more 'restful' than the Canadian group, and they did not judge minor seconds and major sevenths as 'restless' as Canadian listeners tended to. By way of explanation, it can be supposed that, since some genres of Indian classical music frequently use dissonant harmonies, Indians developed higher critical levels of dissonance than their Western counterparts.

2.7. Conclusion

There is still no agreement about the extent to which nature and nurture are involved in C/D perception. Both must play a role, of course, but pinning down exactly what that role is in each case is a harder task. We can say with confidence that C/D perception is to some extent an innate ability, one that is shaped by the physical properties of our auditory system.

However, musical training, learning, and experience undoubtedly help to sharpen our sensitivities to particular qualitative aspects of sound such as pitch and harmonic relations, and enculturation and exposure to musical works help to shape our aesthetic judgements of C/D. This diversity of causes of and influences on C/D perception makes our experience of music that much richer, and helps to keep our musical culture vibrant and interesting.

Chapter 3

Frequency of Occurrence

This work is in preparation for submission to *Music Perception*. Authors: Yuko Arthurs, Amy Beeston, and Renee Timmers

Author contribution

Yuko Arthurs: conducted literature review, prepared experimental stimuli, conducted the experiments, conducted statistical study of the frequency of chord occurrences in musical pieces, analysed the collected data, interpreted the results, prepared all figures and tables, and wrote most of the manuscript.

Dr Amy Beeston: conducted computational analysis of chords, wrote the audio descriptor section of this chapter, read and made suggestions for the draft.

Dr Renee Timmers: gave counsel at all stages of the work, offered feedback, and helped with revision of the draft.

3.1. Introduction

As we saw in Chapter 2, previous studies have revealed that familiarity with a particular style of music helps to shape our expectations, and that this in turn influences our perception of music and of C/D (Bharucha, 1994; Bigand &Pineau, 1997; Roberts, 1986). Familiarity is simply formed by repeated exposure to certain musical events (Zajonc, 1968; 2001). In other words, the frequency of the occurrence of particular musical events is crucial to shaping our perception, and it is the task of this chapter to examine the relationship between the frequency of the occurrence of single chords and our perception of these chords.

A single chord can and often does play a significant role in the listener's experience and internal representation of music. A single chord can, for example, create an expectation for an upcoming chord (Bharucha & Stoekig 1987); it can generate a sense of key (Krumhansl, 1990); it can induce a variety of emotions (Cooke, 1959; Lahdelma & Eerola, 2014); and it can remind the listener of *un signifié* in the manner of a leitmotif, such as the Tristan chord (Nattiez, 1990). A chord gains such power by being played repeatedly, and this repetition helps to reinforce its importance not only within the structure of the musical work, but also in the listener's musical schema. In other words, a chord that appears frequently and at crucial musical moments becomes more important and stable within the underlying system of music (Krumhansl, 1990), and becomes more of a feature of the listener's musical schema than less frequently occurring chords. For example, some intervals and chords that were considered 'dissonant' up until the 13th century (e.g. the major third, the major sixth, major and minor triads) soon became more and more familiar, until, by the time of the Renaissance with their place within Western music firmly established, they came to be regarded as 'fused sonorities' (Parncutt, 2011).

What this shows is that the frequency of a chord's occurrence has a large influence on how we perceive it - and, in particular, on how we perceive its consonance and dissonance (Parncutt & Hair, 2011). This study seeks further evidence of the influence of frequency of occurrence by investigating listeners' perceptions of triads and tetrads, in terms of consonance/dissonance, pleasantness/unpleasantness, stability/instability, and relaxation/tension. We assess listener ratings of these four variables across a variety of chords, and investigate the relationship of these ratings with the frequency of occurrence of each of these chords in selected works by J. S. Bach and The Beatles; and with selected acoustic descriptors of the chords extracted using two MATLAB-based signal processing toolboxes.

3.1.1. Statistical approaches to chord perception: frequency of occurrence

It is thought that listeners acquire an implicit knowledge of music through repeated exposure (Bharucha, 1984). In this way, the listener learns and internalises regularities that organise and constrain the music based partly on the frequency of occurrence of particular musical events. Krumhansl (1985) reported that tones and chords that were judged more important and stable in experiments tended to occur more frequently in some pieces of music, such as in works by Mozart and Schubert, than less important ones did. The importance of frequency of occurrence for learning the structures and systems of music has also been studied using non-Western tonal music, such as traditional Indian music (Castellano, Bharucha & Krumhansl, 1984), Finnish Sami yoik (Krumhansl, Louhivuori, Toiviainen, Järvinen, & Eerola, 1999; Krumhansl, Toivanen, Eerola, Toiviainen, Järvinen, & Louhivuori, 2000: Krumhansl, 2000), and pieces of music created using novel musical systems (Jonaitis & Saffran, 2009; Oram & Cuddy, 1995). Castellano, Bharucha and Krumhansl (1984) demonstrated that exposure to Indian music made Western listeners with no prior familiarity sensitive enough to be able to respond in the same manner as Indian listeners. Both groups of listeners judged the presented tones based on the frequency and duration of their occurrence. A study by Oram and Cuddy (1995) used the probe tone technique to demonstrate that tones appearing more frequently in artificial sequences receive higher ratings for ‘better fit’, although non-musicians were less influenced by this frequency effect. More recently, it has also been reported that a greater frequency of occurrence assists listeners in extracting principles from a set of novel sequences, and can help them to adapt these principles to understand the structure of a new musical system (Jonaitis & Saffran, 2009).

A number of studies have examined the frequency of a chord’s occurrence in different pieces of music (Bronze & Shanahan, 2013; Budge, 1943; Rohrmeier & Cross, 2008). Budge (1943) examined the frequency of the occurrence of diatonic chords in musical pieces from the eighteenth to the nineteenth century and found that chords built on a tonic tone accounted for 41.79 % of the total, whereas chords built on a mediant tone comprised a mere 1.35 % of the total in major mode contexts. Rohrmeier and Cross (2008) found a similar prevalence of very functional chords in Bach’s chorales, such as I, V, and IV, which appear with much greater frequency than less functional, less important ones. Experimental data gathered by Krumhansl (1985, 1990) strongly correlates with Budge’s diatonic chord distribution – chords that appeared more frequently tended to be given higher ratings of ‘fittingness’ with prime scales or chord sequences in experiments using the probe tone technique. In addition, the frequency of the occurrence of particular *notes* had an effect on *chord* ratings: that is, chords consisting of notes that occur frequently in tonal music tended to be judged as fitting better with primes (Krumhansl, 1990).

A second approach considers the *type* of chord, such as a major or minor triad, instead of the harmonic function of a chord in a given scale. Once again, studies reveal an uneven distribution in the frequency of occurrence of different types of chord. For instance, Rohrmeier and Cross (2008) reported that the most prevalent chord type in the chorales of J.S. Bach in both major and minor modes is the major chord (60.8% in major, 44.9% in minor), followed by the minor chord (17.1%, 33.8%), and the major seventh chord (7.1%, 6.1%), whereas the diminished triad accounts for only 2.3% in major modes and 3.3% in minor modes. By contrast, Bronze and Shanahan (2013) reported that, in Jazz pieces from 1924 to 1968, the predominant chord is the dominant seventh, which accounts for 40.3 % of the total, followed by the minor seventh (26.3 %) and the major triad (22.1%), while diminished and augmented chords represent 2.2% and 0.1% respectively. A question that arises here is whether and how the frequency of occurrence of different *types* of chord could influence listeners' perception of chords. It may be that listeners acquire implicit knowledge about different types of chord as well as about the tonal hierarchy of chords, and they may as a result have differing levels of familiarity with these chords according to the frequency of their occurrence. We know that familiar objects are perceived more favourably than less familiar ones, a phenomenon known as 'mere exposure effect' (Zajonc, 2001), and we know also that more commonly occurring tones or sounds become encoded as more important and stable (Bigand, 1997; Krumhansl, 1990). Consequently, it may be expected that listeners will perceive these more frequently occurring particular types of chord more favourably, and for this reason will judge them to be more consonant, pleasant, stable or relaxed.

3.1.2. Psychoacoustical approaches to chord perception

Since consonance is a fundamental aspect of interval perception, it is likely to be important in the perception of chords as well. As reviewed in Chapter 2, the consonance and dissonance (C/D) of intervals has at times been attributed to psychoacoustic effects arising due to the frequency ratio between the two tones present (Helmholtz, 1877/1954; Hutchinson & Knopff, 1978, 1979; Kameoka & Kuriyagawa, 1969; Plomp & Levelt, 1965). The consonance of intervals has also been explained in terms of fusion (Boring, 1942; DeWitt & Crowder, 1987; Schneider, 1997; Stumpf, 1875) and harmonicity (Bidelman & Krishnan, 2009; Cousineau, McDermott, & Peretz, 2012; McDermott, Lehr, & Oxenham, 2010; Tramo, Cariani, Delgutte, & Braida, 2001).

In addition to the psychoacoustic features of sounds, the listener's implicit knowledge of tonal music and their expectations based on this knowledge are important factors in C/D perception and judgement (Bharucha, 1994; Bharucha and Stoekig, 1987; Cazden, 1980; Roberts, 1986; Tillmann, Janata, Birk, and Bharucha, 2008; Tillman, and Lebrun-Guillaud, 2006; Regnault, Bigand, and Besson, 2001).

In comparison with the C/D of individual intervals, the C/D of chords remains little understood. One approach, followed by Hutchinson and Knopff (1978, 1979), Sethares (1998), and by Vassilakis (2005, 2007), computed 'roughness' values to predict the C/D of intervals and chords. Their calculated roughness values are generally consistent with current music theory and with the existing behavioural data (Hutchinson & Knopff, 1979; Johnson-Laird, Kang, & Leong, 2012). However, calculated roughness failed to predict the C/D ranking of diminished and augmented triads (Johnson-Laird, et al., 2012). While the calculated roughness of a diminished triad is higher than it is for an augmented triad (Hutchinson & Knopff, 1979), the behavioural data in fact suggests that diminished triads are perceived as more consonant than augmented triads (Bidelman & Krishnan, 2011; Cook & Fujisawa, 2006; Johnson-Laird, et al., 2012; Roberts, 1986). Bidelman and Krishnan (2011) demonstrated that "neural pitch salience", based on neural activity in the midbrain of participants in response to chords, was a good predictor of the C/D of chords. In their study, chords that were judged to be more consonant elicited stronger neural pitch salience in correspondence with the rank order of C/D judgements made by listeners.

The perception of chords also induces felt and perceived tension in listeners. As we saw in Chapter 2, various empirical studies report that acoustical features such as dynamics, tempo, pitch height, and timbre are contributory factors to the creation of tension For instance, musical works of louder volume, faster tempo, and those with an extremely high or low pitch register trigger greater tension, and these features also interact with each other (Burnsed & Sochinski, 2001; Farbood, 2012; Farbood & Upham, 2013; Granot & Eitan, 2011; Ilie & Thompson, 2006; Krumhansl, 1996 ; Paraskeva & McAdams, 1997). In addition, sensory dissonance, and in particular roughness, has a large influence on the perception of instability and tension (Lerdahl & Krumhansl, 2007). Instrumental sounds with roughness trigger tension (Pressnitzer, McAdams, Winsberg & Fineberg, 2000); and chords with more roughness are perceived as more tense when in a harmonic context (Bigand, Parncutt & Lerdahl, 1996), and as more unstable even in atonal music (Dibben, 1997).

3.1.3. Psychological approaches to chord perception

Psychological studies have tended to focus on the relationship between chords – they have sought to establish facts about the tonal hierarchy of chords, and have tried to offer empirical proof that the tonal hierarchy in the listener's musical schema reflects the highly structured system of music theory. Probe tone techniques, which ask listeners to judge to what extent a target stimulus fits with an initial stimulus (priming), have demonstrated that the musical schemata of Western listeners are to a large extent shaped by the music theory of Western tonal music. Listeners perceive the tonic tone and chords that feature in the prime stimulus as being most fitted to the prime, followed by the dominant and subdominant tones (Krumhansl, 1979). Bharucha and Stoekig (1987) demonstrated that listeners' judgements of whether the second chord (the target) is in or out of tune were made more accurately and quickly when the second chord was more closely related to the first (the prime). This result indicates that even a single chord is sufficient to evoke a tonal hierarchy and can activate certain expectations in listeners.

The tonal hierarchy of chords is based on their position within the scale degree of chords, and not merely on the pitch frequency of their component notes. For example, a major chord of C-E-G would be the tonic chord for the key of C major, but the very same chord would be the subdominant chord for the key of G major. Also, despite having two of the same component notes as the minor chord E-G-B, the major chord C-E-G has a closer relationship to the major chord G-B-D with which it shares only one tone, since C-E-G and G-B-D stand in a tonic-dominant relationship. These examples illustrate that the tonal hierarchy of chords and the relationships that stand between chords are dependent more on context than they are on acoustic properties (Tillmann, 2000, 2008). A study by Tekman and Bharucha (1998) further examined whether listeners' expectations of a target chord following a prime chord were influenced more by the tonal relationship between the two chords or by their acoustic similarities, and whether this varied according to the duration of the prime stimulus.

Two types of target chord were used: firstly, ones that were harmonically close but that shared none of the same tones (such as a D major chord following a C major prime chord); and secondly, chords that were harmonically distant, but that included shared tones and that were therefore acoustically similar (such as an E major chord following a C major prime chord). Listeners judged whether the target chord was in-tune or out-of-tune, and quicker and more accurate judgements of the target chord indicated greater listener expectation for the chord. The findings were that acoustically similar chords were judged more accurately and quickly than harmonically close chords when the prime chord was short, whereas harmonically close chords were better judged than acoustically similar chords when the prime chord was longer. Together these results suggest that the listener's expectation regarding a chord arises partly from the chord's acoustic content, from its context, *and* from the listener's implicit knowledge of the tonal hierarchy.

Various empirical studies have also attributed the perception of stability and tension to the tonal hierarchy of chords, and to listener expectations as shaped by their musical schemata. Listeners perceive more important tones in the musical hierarchy as more stable (Bigand, 1997) and as less tense (Bigand, Parncutt & Lerdahl, 1996) than hierarchically less important ones. In addition, it has been found that the most stable tonic at the end of a cadence will elicit the greatest sense of completion in most listeners (Tillman and Lebrun-Guillaud, 2006); and that tones with greater stability are processed more accurately and quickly than less stable tones (Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003; Bigand, Tillmann, Poulin-Charronnat, and Manderlier, 2005; Tillmann, & Marmel, 2013). Expectations play an important role in creating tension, especially when any given expectation is violated. Tension occurs when factors such as tempo, dynamics, pitch height, and tonal hierarchy deviate from the listener's musical schema (Huron, 2006; Lerdahl & Krumhansl, 1997). Unexpected chords, or chords appearing in unexpected positions in a harmonic progression, tend to generate more tension (Steinbeis, et al., 2008), and elicit a larger negative response in the brain such as the early right anterior negativity (ERAN) (Koelsch, Gunter, Friederici, & Schroeger 2000; Leino, Brattico, Tervaniemi, & Vuust, 2007; Loui, Grent-'t-Jong, Torpey, & Woldorff, 2005; Maess, Koelsch, Gunter, & Friederici, 2001), and mismatch negativity (MMN) (Brattico, Näätänen & Tervaniemi, 2002).

3.1.4. The relationship between Consonance, Pleasantness, Stability and Tension

In previous studies, judgements of consonance and dissonance have been shown to be often coincident, respectively, with judgements of pleasantness and unpleasantness (Johnson-Laird, et al., 2012; Roberts, 1986), stability and instability (Bigand & Parncutt, 1997; Bigand, Parncutt & Lerdahl, 1996), and relaxation and tension (Parncutt & Hair, 2011). However, the question of whether these various terms denote one and the same quality of chords, or whether instead they denote different qualities, has not yet been fully resolved.

It is a relatively common notion that a chord's being consonant is equivalent to its being pleasant, while dissonance is considered unpleasant (Tenny, 1988). Indeed, a study by van de Geer, Levelt and Plomp (1962) that used semantic differentials found that the notions of consonance, beauty and euphony occupy the same dimension in semantic space, indicating that consonant sound tends to be evaluated as aesthetically pleasing. On the basis of this congruency between consonance and pleasantness, studies concerning the perception of C/D of chords have at times therefore used a 'pleasant/unpleasant' metric in place of a 'consonant/dissonant' metric when evaluating the C/D perception of chords (Cook & Fujisawa, 2006; Johnson-Laird, et al., 2012; McDermott et al., 2010). However, some evidence casts doubt on this strategy. In a study by Guernsey (1928), intervals that were judged as most fused and smooth were not also evaluated as most pleasant by musically trained listeners. Further, Arthurs and Timmers (2015) found that some listeners did not evaluate C/D and P/U in the same way, and hence their ratings for the C/D of chord sequences did not correlate with their ratings for P/U ($r < .50$, $p > .05$). These examples point to the need to examine the relationship between the perception of the C/D and P/U of chords in isolation.

3.1.5. The effect of musical training

Musical training appears to influence chord perception, though the reported effects vary according to the aspect of the chord in question. Musicians are generally more sensitive to C/D than non-musicians (Brattico, et al., 2005; Itoh, Suwazono, and Nakada, 2010; Roberts, 1986; Rogers, 2010; Schön, Regnault, Ystad, & Besson, 2005). Although both musicians and non-musicians have the same aversion to roughness (Cousineau, et al., 2012; McDermott, et al., 2010), musicians in particular rely to a greater extent on their understanding of harmonicity than on roughness when judging C/D (Kung, Hsieh, Liou, Lin, Shaw, & Liang, 2014; McDermott, et al., 2010). The difference between musicians and non-musicians can be observed in their brain activity. For example, differences between musicians' C/D judgements of intervals and those of non-musicians were observed in event-related brain potentials (ERPs) data (Schön, et al., 2005); consonant and dissonant sounds were found to activate different regions of the brains of musicians and non-musicians (Minati, Rosazza, D'Incerti, Pietrocini, Valentini, Scaioli, Loveday, & Bruzzone, 2009); and musicians' brainstem responses to dissonant intervals were found to be more robust and coherent than those of non-musicians (Lee, Skoe, Kraus, & Ashley, 2009).

An extensive musical training seems to make listeners sensitive not only to the sonority but also to the harmonic structure of Western tonal music. Schellenberg and Trehub (1994) established that listeners with more extensive musical training relied more on the prevalence of intervals in Western music than on the mere simplicity of the frequency ratios of two tones when judging the pleasantness of intervals. Listeners with more extensive musical training perceived intervals with simple frequency ratios, such as the major third or the major sixth, as more pleasant than intervals with even simpler frequency ratios, such as the octave or the perfect fifth (Malmberg, 1918; van de Geer, Levelt, & Plomp, 1962). According to Schellenberg and Trehub (1994), this may be explained by the fact that the major third and the major sixth are more common in Western music than either the octave or the perfect fifth, and that therefore the judgements of musically trained listeners were influenced by their familiarity with these intervals. However, some aspects of chord perception seem to be less susceptible to the influence of musical training. In terms of judgements of the aesthetic qualities of chords such as pleasantness, musical training was found to have 'no reliable effect' on the pleasantness ratings of chords either in isolation (Johnson-Laird, et al., 2012), or in context (Roberts, 1986). Additionally, musicians' judgements of the semantic connotations of the C/D of intervals were not dissimilar from those of non-musicians (Costa, Bitti, & Bonfiglioli, 2000).

Similarly, there is little evidence to indicate that musical training influences the perception of stability. Bharucha and Krumhansl (1983) found no difference between musicians and non-musicians in harmonic hierarchies of the perceived stability of chords. Similarly, Bigand (1997) found no apparent difference between musicians' and non-musicians' perceptions of stability in melodic sequences, concluding: "the explicit learning of music may not be necessary to perceive subtle structures in tonal musical sequences". However, Bigand et al., (1996) did uncover some influence from musical training in their participants' perceptions of tension. Musically trained listeners' tension ratings were positively correlated with the roughness of chords, and negatively correlated with pitch distance and the tonal stability of chords. Further, effects of chord type and mode were clearly observed in musicians, whose tension ratings for minor and seventh chords were significantly higher than for major chords (Bigand et al., 1996). Lahdelma and Eerola (2014) likewise found that musically trained listeners tended to give higher ratings for augmented triads than less musical listeners. Taken together, these results suggest that musical training enhances sensitivity both to the acoustic features of chords (such as harmonicity, roughness, and the frequency relationships between a chord's constituent tones), as well as to tonal hierarchy.

3.2. Aims of the present study

The main purpose in presenting this study is to demonstrate the importance of the frequency of the occurrence of different types of chord when it comes to the listener's perception of these chords in isolation. As previously mentioned, studies have shown that the frequency of a chord's occurrence in a piece of music is unevenly distributed (Bronze and Shanahan, 2013; Budge, 1943; Rohmeier and Cross, 2008), and that tones and chords that listeners judge as being more hierarchically important and stable appear more frequently (Krumhansl, 1985, 1990). From this, it can be hypothesized that frequently occurring chords may be perceived as more consonant, pleasant, stable and relaxed than less frequently occurring ones. Further, we hope to discover which has the greater influence on the listener's perception of a chord: its acoustic features, or its frequency of occurrence. In relation to this,, there is the question of whether the frequency of a chord's occurrence might ever override the influence of its acoustic features. For instance, if a chord has a higher roughness value than others but also occurs more frequently (e.g. a diminished chord might have a higher roughness value and appear more often than a minor chord), the question is whether the listener's perception of it will be influenced more by its roughness or by the frequency of its occurrence. If the former is the case then the chord will be perceived as more dissonant than the others, whereas if it is the latter then the chord will be perceived as more consonant.We employed as stimuli 12 different chord types (5 triads and 7 tetrads), all with roots of C or F#, and all played on the piano and organ, making 48 chords in total. Four approaches were taken. Firstly, as an estimate of the frequency of the occurrence of each chord type and hence of participants' likely familiarity with them, we counted the number of times each chord type appears in J.S. Bach's Italian Concerto, and in The Beatles' 30 best-selling UK hits. Secondly, certain key acoustic descriptors of the 48 chords were extracted using MIR toolbox (Lartillot and Toiviainen, 2007) and Timbre toolbox (Peeters, Giordarno, Susini, Misdariis, and McAdams, 2011). Thirdly, participants were asked to rate their level of familiarity with each of the two timbres used in the experiment (Experiment 1). The last approach is an experiment to collect data on listeners' perceptions of these chords (Experiment 2). The data we gathered from the first three approaches (the frequency of each chord's occurrence, the extracted acoustic descriptors of the 48 chords used, and listeners familiarity ratings on two timbres) were statistically assessed in order to analyse the relationship between these and the behavioural data gathered from Experiment 2.

We include seven tetrads as musical stimuli; however we do not aim to establish a theory of the C/D of seventh chords here, but merely to collect data on the perception of seventh chords. In music theory, chords containing dissonant intervals such as the diminished third or the augmented third are categorised as dissonant (Piston, 1960: Sadai, 1980). Major chords most frequently appear as the important "primary triads" of I, IV, and V (Benward & Saker, 2012; Morris, 1946). The tetrads used in this study are exclusively seventh chords. The augmented major seventh is considered a particularly dissonant seventh due to the fact that it features the augmented triad and the major seventh (Sadai, 1980). The major-minor seventh (also known as the dominant seventh) has a strong dominant character that tends to resolve onto the tonic and appears frequently in music (Benward & Saker, 2012; Sadai, 1980). By contrast, some seventh chords such as the half-diminished seventh or diminished seventh are enharmonic and ambiguous in terms of their chord function. According to music theory, the seventh has the effect of adding dissonance to triads, and therefore all seventh chords are dissonant (Sadai, 1980). We will examine whether seventh chords are indeed perceived as more dissonant than any triad due to the presence of the seventh, or whether certain triads can be more dissonant due to their triadic structure (e.g. whether augmented triads are more dissonant than major sevenths).

We adopt two timbres, organ and piano, for all chord types in order to further examine the effect of timbre on the listener's perception of chords. Previous studies revealed that the listener's tension responses to music varied according to the timbre in which the stimuli were played (Paraskeva & McAdams, 1997). Also, chords induce different emotions in the listener depending on the timbre in which chords are played

(Lehdelma & Eerola, 2014). Lehdelma and Eerola (2014) have reported that chords played using strings tend to trigger more nostalgia, melancholy, or sadness than chords that use a piano timbre, whereas chords using a piano timbre induce more happiness and joyful emotions. We predict that chords played using a church organ timbre will be perceived as more dissonant, unpleasant, unstable and/or tense than those using a piano timbre due to the rich overtones of the organ timbre. Also, the piano timbre may be more familiar for listeners than the church organ, and this familiarity may be influential. As familiarity in general is one of the most important factors in music perception (Huron, 2006), it may be the case that familiarity with timbre is equally important: the more familiar the timbre, the more positively the chord will be perceived. We will collect data on listeners' familiarity with both timbres as one measure of the influence of timbre.

In addition, we will also examine the relationship between the perception of consonance, pleasantness, stability, and tension in isolation, and the influence of musical training on chord perception. Participants in the experiment were asked to rate 12 types of chords according to each of those four variables. As for the influence of musical training, instead of employing the classic dual categorization of participants into musicians and non-musicians, participants were categorised according to three different levels of musical experience: those with a music degree; those who had had a moderate amount of music lessons; and those who had had no formal musical training. This tripartite categorisation was used in order to gather richer data about the influence of musical training on chord perception.

Table 3.1.

Thirty songs of The Beatles used for frequency of occurrence measure

Ranking Number	Song titles
1	She Loves You
2	I Want To Hold Your Hand
3	Can't Buy Me Love
4	I Feel Fine
5	Day Tripper
6	We Can Work It Out/ Hey Jude
7	From Me To You
8	Help!
9	Hello Goodbye
10	Get Back
11	Paperback Writer
12	All You Need Is Love
13	Yellow Submarine/ Eleanor Rigby
14	Ticket To Ride
15	Magical Mystery Tour EP
16	A Hard Day's Night
17	Penny Lane
18	Lady Madonna
19	Love Me Do
20	Please Please Me
21	The Ballad Of John And Yoko
22	Let It Be
24	Something/ Come Together
26	Yesterday
28	Baby It's You
29	Back In The USSR
30	Strawberry Fields Forever

3.3. Frequency of occurrence of chords from The Beatles' songs and J. S. Bach's keyboard pieces

We counted the number of times each chord type appeared in The Beatles' songs and in J.S. Bach's keyboard works. In the case of The Beatles, we chose 30 best-selling songs in the UK from BBC chart (http://www.beatlesbible.com/2009/09/01/bbc-chart-reveals-best-selling-uk-beatles-songs/) (Table 3.1.), and counted the guitar chord symbols indicated in the score of *the Beatles: complete scores* (1993). The percentage occurrence of each chord type was calculated after counting. For Bach, we analysed three movements of the *Italianishes Konzert* BWV971, and counted the number of times each chord appeared in each movement. We counted all and only those chords that formed part of the fundamental harmonic progression of the three movements, and ornamental tones were not considered constituent parts of the chords. Figures 3.1 shows the percentage occurrence of each chord type in the works of Bach and The Beatles, respectively. Unsurprisingly, major triads are the most prevalent in both, followed by the dominant seventh, and then by minor triads. Bach's music uses a greater variety of chords, such as diminished triads and diminished sevenths, than feature in The Beatles' guitar chord symbols; however, both oeuvres shared very similar general trends in terms of frequency of chord occurrence according to Spearman's rank order correlation: $r_s(12) = .692$, $p = .013$.

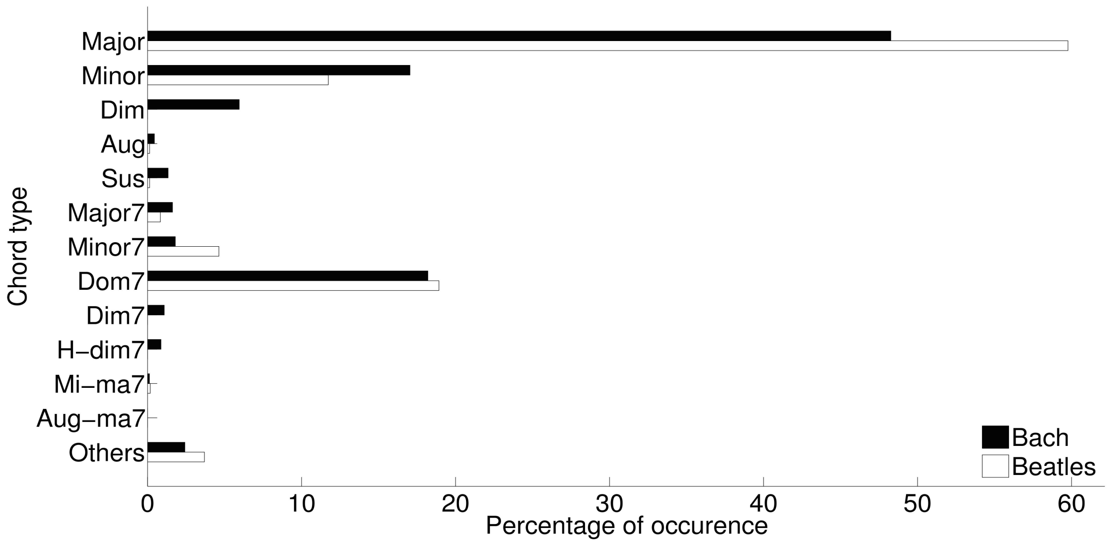

Figure 3.1. The percentage occurrence of each chord type in J.S. Bach's Italianische Konzert, BWV 971, and in The Beatles' 30 best-selling UK hits.

Abbreviations: Major = major triad, Minor = minor triad, Dim = diminished triad, Aug = augmented triad, Sus = suspended chord, Major7 = major seventh, Minor7 = minor seventh, Dom7 = dominant seventh, Dim7 = diminished seventh, H-dim7 = half-diminished seventh, Mi-ma7 = minor-major seventh, Aug-ma7 = augmented-major seventh

3.4. Experiment 1: Familiarity with timbre

An experiment was conducted to gather data on listeners' familiarity with organ and piano timbre.

3.4.1. Method

Participants

Thirty-three adults (Male: 13, Female: 20. Age range: 19 to 69 years, with a median age of 24 years) took part in the experiment. Participants were divided into three groups according to their musical experience: Musicians were those who had a music degree (eight participants); Learners were those who had had music lessons for a total of 3 to 10 years, with the average being 7.88 years (17 participants); and the remaining eight who had had no musical lessons or training of any sort were Non-Musicians.

Materials

Nine chords (major chords on C-sharp and G, and a minor chord on G, each with Organ and Piano timbre) of 1.00 second's length were used. Stimuli were created by a software program Cubase, using Church Organ for chords with organ timbre and YAMAHA S90ES Piano for chords with piano timbre.

Procedure

Stimulus chords were presented in a random order through a pair of headphones at a comfortable volume. Participants rated their familiarity with the timbres of these chords on 7-point scale (1 extremely unfamiliar to 7 extremely familiar) by pressing a button on a computer keyboard.

3.4.2. Results

Figure 3.2. shows the mean and standard error of ratings for the two timbres by the three groups. The data from the familiarity ratings reveals that Piano was more familiar than Organ. A mixed model ANOVA with two factors (Timbre and Musical Background) shows that there was a significant main effect of Timbre: $F(1, 30) = 14.592$, $p = .001$, $r = .57$, and Musical Background: $F\ (2, 30) = 14.251$, $p < .001$, r=.69. A pairwise comparison shows that the differences between each group were all significant ($p < .05$), and that familiarity ratings increased with musical expertise: musicians showed greater familiarity with both sounds than learners, and much more than non-musicians. There was no interaction between the effects of Timbre and Musical Background ($p = .170$).

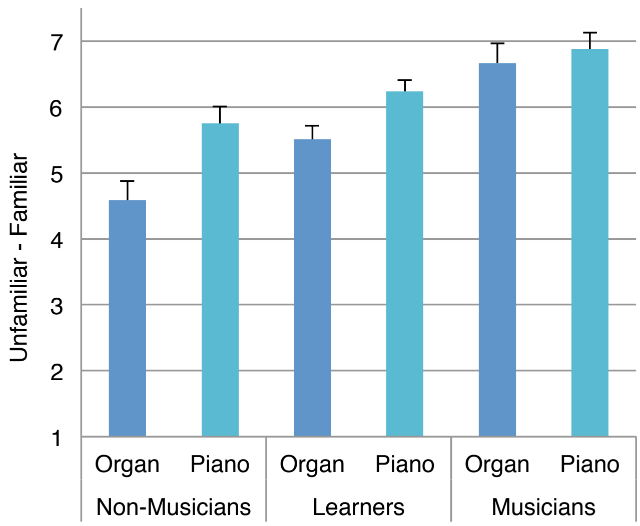

Figure 3.2. Mean ratings of familiarity with each timbre

3.5. Acoustic features

The aim of the computational sound analysis was to represent each sound stimulus with an array of numerical values that are termed 'audio descriptors', and that are assumed to characterise certain properties of the audio signal. For convenience, two widely-used signal processing libraries were selected for the current study based on their availability, MATLAB-compatible code bases, and substantial supporting documentation: the Timbre Toolbox (Peeters et al., 2011) and the MIR Toolbox (Lartillot and Toiviainen, 2007). The remainder of this section describes the factors that motivated the selection of audio descriptors presented in Table 3.2.

Pre-processing

Since stereo data was presented to human listeners in this study, the two selected signal processing libraries were firstly checked for compatibility with 2-channel audio files. Secondly, experimental stimuli were batch-normalised prior to the computational analyses by ensuring that the root-mean-square (RMS) energy level of each sound-file was equalised. This step minimised the impact of individual variability in the default normalisation procedures (documented or otherwise) of the various audio descriptor algorithms. Each toolbox then processed the sound files individually, typically by fragmenting the audio sample into a series of windowed input frames, and computing the required value repeatedly for each of these short duration segments. A measure of the central tendency of these segments was provided at output of the computational analysis: the median value in the case of the Timbre Toolbox, and the mean for the MIR Toolbox algorithms. The temporal variation of the sound was additionally stated in terms of either the inter-quartile range (Timbre Toolbox) or standard deviation (MIR Toolbox).

Time-domain analyses

The experimental stimuli comprise conceptually similar items: a single chord, of fixed duration, synthesized at a pre-determined signal level on one of two virtual instruments. Nonetheless, a degree of variation might arise in the temporal envelope of the signal due to the particular instrumental timbres selected since piano sounds typically have a strong onset and decay rapidly, whereas organ tones are sustained throughout the duration of the chord. The audio signals were thus segmented into short frames (every 60 ms) and the energetic content of the signal was calculated within each frame, producing an *RMS-energy envelope* that traces the signal power through time.

Spectral-domain analyses

Spectral descriptors disregard the temporal evolution of the sound, and instead consider the distribution of energy across frequency. The audio signals were again segmented into short frames, and a spectral representation of the sound power within each frame was computed using the squared-amplitude values of the Short Term Fourier Transform (STFT) of the signal. A variety of statistical processes then summarised the signal content, as follows. Firstly, the *spectral centroid* (the first statistical moment of the spectrum) represents its spectral centre of gravity. Secondly, the *spectral skewness* quantifies the asymmetry of the spectrum about its mean. Two further measures address the tonal vs. noise content of the signal. *Spectral flatness* compares the geometric and arithmetic means of the signal to calculate the tonal vs. noise content of the signal, using the insight that white noise produces a flat spectrum while a single sinusoidal component appears as a peak in the spectrum. The *spectral crest* descriptor similarly considers the tonal vs. noise balance of the signal, in this

Table 3.2.

Audio descriptors extracted by Timbre Toolbox and MIR Toolbox.

Audio descriptors were computed for each of the experimental stimuli in spectral (S), temporal (T), spectro-temporal (ST) and harmonic (H) domains. Ten values resulted from Timbre Toolbox (TT) analyses, comprising the median and interquartile range (iqr) of the temporal energy envelope values, and of spectral centroid, skewness, flatness and crest. A further seven values resulted from MIR Toolbox (MT) analyses, which computed the mean value and standard deviation (std) of spectral regularity, flux and roughness in addition to the key-strength probability relative to the corresponding major key (C or F#).

Domain	Toolbox	Audio descriptor	Explanation
T	TT	RMS-energy envelope (median, iqr)	Mean and interquartile range of the temporal energy envelope values.
S	TT	Spectral centroid (median, iqr)	Geometric center of the spectrum.
S	TT	Spectral skewness (median, iqr)	Asymmetry of the spectrum about its mean.
S	TT	Spectral flatness (median, iqr)	Flatness or peakiness of the signal (comparing tonal/noise components).
S	TT	Spectral crest (median, iqr)	Comparison of maximum and mean of the spectral values (again relating to tonal/noise balance).
S	MT	Spectral regularity (mean, std)	Degree of uniformity in the neighbouring peaks of the spectrum.
ST	MT	Spectral flux (mean, std)	Degree of change in the temporal evolution of the spectrum (frame-by-frame).
ST	MT	Spectral roughness (mean, std)	Estimation of sensory dissonance.
H	MT	Key strength (probability)	Key-strength probability relative to the corresponding major key (on C or F#).

case using a frame-by-frame comparison between the maximum value and the arithmetic mean of the spectrum. The *spectral regularity* measure compares the degree of uniformity (or otherwise) in the amplitude of adjoining peaks in the spectrum.

Spectro-temporal analyses

A function of both time and frequency, *spectral flux* computes the frame-by-frame difference observed in the spectrum as the sound evolves, thereby highlighting temporal positions of important spectral changes. Secondly, a roughness value is computed to estimate the sensory dissonance that a human listener would have experienced due to beating between pairs of peaks in the spectrum.

Harmonic analyses

The final audio descriptor computes a value for *key strength* that quantifies the probability that a given chord is associated with the major key of its corresponding root pitch (C or F#, as appropriate). To achieve this, the spectrum is wrapped to redistribute the (re-normalised) energy into a single octave range, constituting the 12 equally-tempered pitches of the standard Western music stave. The resulting chromagram is then cross-correlated with pre-defined profiles governing the expected pitches for each of the possible key candidates.

3.6. Experiment 2: Listeners' perception of 12 chords

An experiment was carried out in order to measure listeners' perception of 12 different chords in terms of consonance, pleasantness, stability, and relaxation.

3.6.1. Method

Participants

The same 33 participants as took part in Experiment 1 'Familiarity with timbre' took part in this experiment.

Materials

Five triads and seven tetrads heard in two different timbres were employed as musical stimuli (Figure 3.3). The types of chord used were: major, minor, augmented, diminished, suspended, major seventh, minor seventh, dominant, diminished seventh, half-diminished seventh, minor-major seventh, and augmented-major seventh. These 12 types of chord were built on either C4 (261.63 Hz) or F#4 (369.66Hz) in root and close position, and presented in two different timbres (Organ and Piano), thus making a total of 48 chords. Chords with organ and piano timbres were created by Cubase, using Church Organ and YAMAHA S90ES Piano, respectively. The duration of each chord was 1.00 second.

Procedure

There were four sessions, each of which focused on one of four variables (consonance, pleasantness, stability, and tension). All 48 chords were played in a random order in each session, and participants rated each variable on a 7-point scale. As well as the chords within each session appearing randomly, the four sessions themselves were presented to participants in a random order. Experiments were run using PsyScope software, and sound stimuli were presented binaurally, through a set of headphones with a comfortable level of loudness. Participants were able to adjust the volume if necessary prior to the experiments. Experiments were conducted individually.

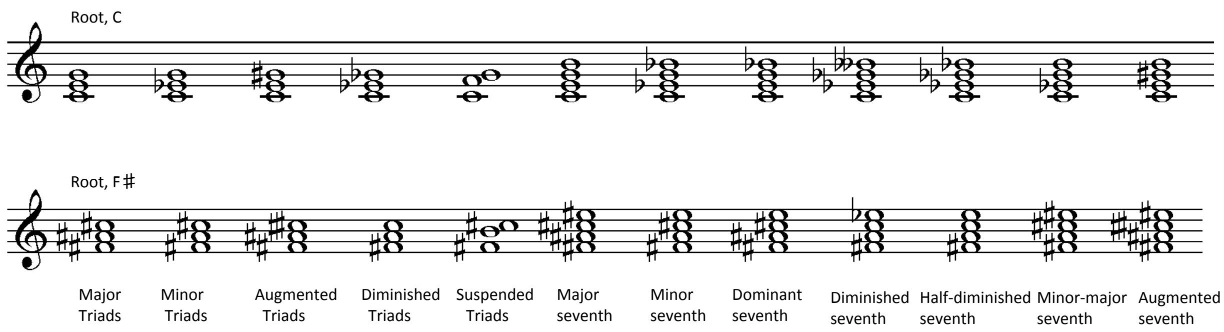

Figure 3.3. Twelve types of chord with roots of C and F♯ were used as musical stimuli. Four triads (major, minor, augmented, diminished), a suspended chord, and seven sevenths (major, minor, dominant, diminished, half-diminished, minor-major, and augmented seventh) built on either C or F ♯, were played either using an Organ or Piano timbre, yielding 48 musical stimuli in total.

3.6.2. Results

Participants evaluated the consonance, pleasantness, stability and relaxation levels of each chord on a 7-point scale (1 very negative, 4 neither to 7 very positive). Figure 3.4. shows the order of chords heard with Piano timbre, from the chord judged the most consonant to the most dissonant. As expected, major triads were the most consonant of the twelve chord types. Dominant and suspended chords were judged to be relatively consonant, whereas augmented triads, augmented major sevenths, and minor-major sevenths were more dissonant than others, although they were judged to be 'neither'. It is interesting that triads and tetrads were evenly spread out: that is, triads, despite having a less complicated structure than tetrads (in terms of the numbers of notes, intervals, and partials they contain), are not necessarily considered any more consonant than tetrads. For instance, the dominant seventh is judged more consonant than augmented and diminished triads, while the minor seventh (along with the minor triad) is perceived as *moderately consonant*. Instead, C/D judgements tend to depend more on the type of chord in question, irrespective of whether it is a triad or tetrad.

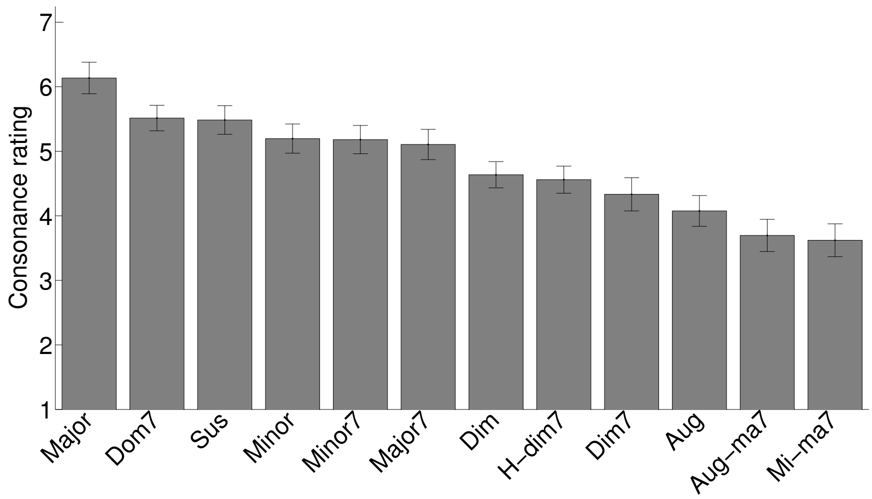

Figure 3.4. Mean ratings of chords' C/D for each timbre

ANOVA

The effect of Timbre

A three-way ANOVA with Timbre and Chord Type as within-subjects factors and Musical Background as between-subjects was computed to assess the ratings for C/D, Pleasantness, Stability, and Tension/Relaxation. Table 3.3. shows the results of pairwise comparison between each chord's mean of C/D ratings. As for the effect of Timbre, significant main effects of timbre were found in the ratings for C/D: $F(1, 30) = 17.463$, $p < .001$, $\eta^2_p = .368$, for Pleasantness: $F(1, 30) = 32.824$, $p < .001$, $\eta^2_p = .522$, and for Tension/Relaxation: $F(1, 30) = 25.108$, $p < .001$, $\eta^2_p = .456$, using Greenhouse-Geisser corrections for violations of sphericity. There was no significant main effect of Timbre on Stability ratings ($p = .091$). The chords with Piano timbre were always judged more consonant, pleasant, and relaxed than those with Organ timbre.

Table 3.3.

Mean differences between C/D ratings of chords.

	Major	Minor	Dim	Aug	Sus	Major7	Minor7	Dom7	Dim7	H-dim7	Mi-ma7
Major											
Minor	.833*										
Dim	1.420*	0.588									
Aug	2.067*	1.235*	-.647*								
Sus	.731*	-0.102	-0.689	-1.336*							
Major7	1.178*	0.346	-0.242	-.889*	0.447						
Minor7	1.032*	0.199	-0.388	-1.036*	0.301	-0.146					
Dom7	0.575	-0.258	-.846*	-1.493*	-0.156	-.604*	-0.457				
Dim7	1.849*	1.016*	0.429	-0.219	1.118*	0.671	.817*	1.274*			
H-dim7	1.598*	0.765	0.178	-0.469	.867*	0.42	0.566	1.023*	-0.251		
Mi-ma7	2.591*	1.758*	1.170*	.523*	1.860*	1.412*	1.559*	2.016*	.742*	.993*	
Aug-ma7	2.376*	1.543*	.955*	0.308	1.645*	1.197*	1.344*	1.801*	0.527	.778*	-0.215

The effect of Chord Type

As for the effect of Chord Type, there were significant main effects for all ratings, C/D: $F(5.59, 167.697) = 32.512$, $p < .001$, $\eta^2_p = .520$, Pleasantness: $F(3.92, 117.801) = 20.397$, $p < .001$, $\eta^2_p = .405$, Stability: $F(5.268, 158.042) = 18.411$, $p < .001$, $\eta^2_p = .380$, and Tension/Relaxation: $F(4.99, 149.956) = 24.830$, $p < .001$, $\eta^2_p = .453$, using Greenhouse-Geisser corrections for violations of sphericity.

The effect of Musical Background

The between-subjects factor of Musical Background was found to have no significant main effect on any of the four ratings: C/D, $p = .103$; Pleasantness, $p = .552$; Stability, $p = .064$; Relaxation, $p = .149$.

The interaction between Timbre and Chord Type

There was also a significant interaction between the effect of Timbre and Chord Type for Tension/Relaxation ratings: $F(11, 330) = 2.145$, $p = .017$, $\eta^2_p = .067$. However, no significant interaction was found between other ratings: C/D, $p = .766$; Pleasantness, $p = .094$; Stability, $p = .333$. A one-way ANOVA with Chord Type as an independent variable was carried out for Organ and Piano separately in order to further investigate the effect of Chord Type on Tension/Relaxation ratings. There was a significant main effect of Chord Type on Tension/Relaxation ratings for Organ: (5.56, 178.17) = 21.350, $p < .001$, $\eta^2_p = .400$, and on those for Piano (5.05, 161.720) = 15.663, $p < .001$, $\eta^2_p = .329$, which shows a slightly larger size of effect for Organ than for Piano. Figure 3.5. plots the mean Tension ratings for Organ and Piano. It can be seen that the major seventh was rated as much more tense for the Organ than for the Piano, and the difference between the two timbres is particularly large for this chord when compared to others.

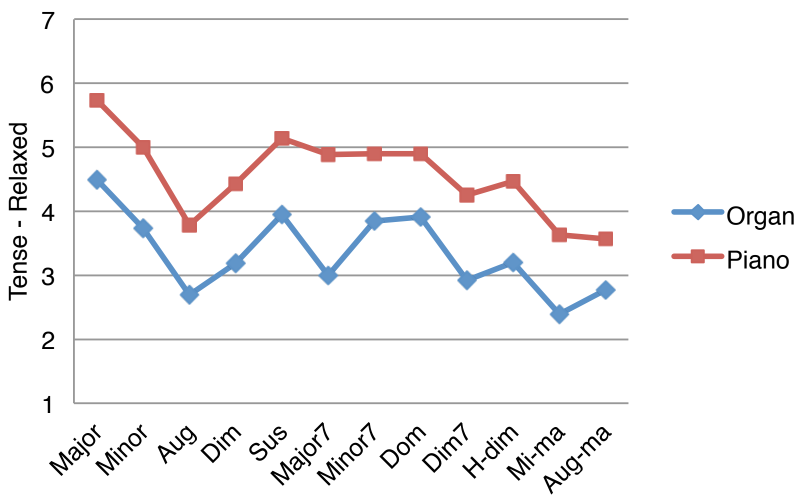

Figure 3.5. Differences between Relaxation ratings of Organ and Piano

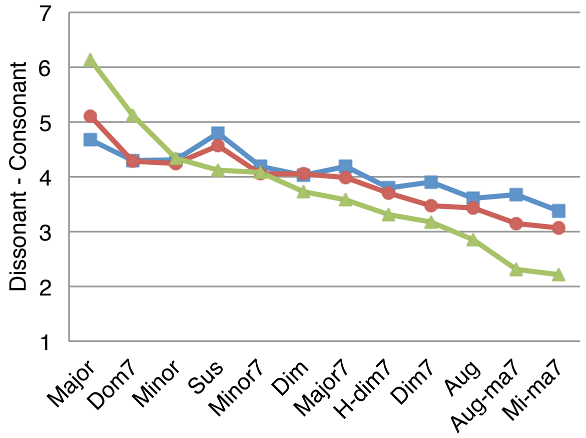

Figure 3.6. Differences in C/D ratings between the three groups. Chords were plotted according their ordering by the Musicians group, from most consonant to most dissonant.

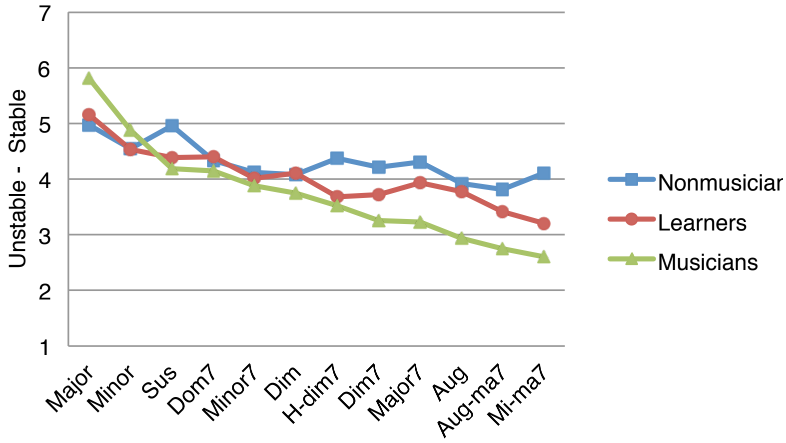

Figure 3.7. Stability ratings of the three groups

The interaction between Timbre and Musical Background

No significant interaction between Timbre and Musical Background was found for any of the ratings: C/D, $p = .548$; Pleasantness, $p = .500$; Stability, $p = .953$; Relaxation, $p = .172$.

The interaction between Musical Background and Chord Type

There was interaction between the effect of Chord Type and Musical Background for C/D ratings: $F(11.18, 167.697) = 4.13$, $p < .001$, $\eta^2_p = .216$, Stability: $F(10.53, 158.042) = 2.126$, $p = .023$, $\eta^2_p = .124$, and for Tension/Relaxation: $F(9.99, 158.042) = 2.538$, $p = .007$, $\eta^2_p = .145$, but not for Pleasantness ratings ($p = .086$). A post-hoc one-way ANOVA was conducted to examine the difference between the three groups' ratings for these three variables in more detail. As can be seen from Figures 3.6. and 3.7, there were significant differences between each of the three groups, mainly in their judgements of chords with more negative valence, which suggests that the perception of dissonance, unpleasantness, instability and tension—and to a lesser degree the perception of the positive counterparts of these qualities—is influenced by musical background. Musicians tended to perceive 'dissonant' chords (such as augmented, augmented major seventh, and minor-major seventh chords) as more dissonant, unstable and tense than non-musicians; conversely, they perceived major chords as more consonant and pleasant than non-musicians. Musicians' ratings for chords were more varied than non-musicians, which may indicate that musicians are better able to discern the quality of different chords.

The interaction among Timbre, Chord Type, and Musical Background

Lastly, this mixed three-way ANOVA found there was no significant interaction among Timbre, Chord Type and Musical Background on any of the four ratings: C/D, $p = .607$; Pleasantness, $p = .502$; Stability, $p = .065$; Relaxation, $p = .165$.

Correlation between Consonance, Pleasantness, Stability and Relaxation

Pearson's product-moment coefficients were computed to assess the relationship between the means of each chord's rating (48 in total: 12 types, 2 roots, and 2 instruments) for Consonance, Pleasantness, Stability and Relaxation. All pairs were positively correlated. In particular, a strong correlation was found between Pleasantness and Relaxation: $r = .977$, $df = 46$, $p < .001$. Consonance ratings were strongly correlated with ratings for the other three dimensions (Consonance and Pleasantness: $r = .929$, $df = 46$, $p < .001$, and Stability: $r = .923$, $df = 46$, $p < .001$, and Relaxation: $r = .923$, $df = 46$, $p < .001$), which means that more consonant chords were also judged to be more pleasant, stable and relaxed. However, when we examine each group separately, the story is slightly different. As Table 3.4. shows, musicians' ratings of Consonance did not significantly correlate with the other three dimensions,

Table 3.4.

Correlation between the four variables per group

		Consonance			Pleasantness			Stability		
		Musicians	Learners	Non	Musicians	Learners	Non	Musicians	Learners	Non
Pleasantness	*r*	.168	.607	.741						
	p	.254	.000	.000						
Stability	*r*	.204	.423	.651	.848	.806	.710			
	p	.165	.003	.000	.000	.000	.000			
Relaxed	*r*	.245	.578	.686	.921	.940	.870	.856	.763	.761
	p	.093	.000	.000	.000	.000	.000	.000	.000	.000

although other pairs (Pleasantness and Stability, Pleasantness and Relaxation, Stability and Relaxation) were positively correlated for all groups.

Factor analysis

In order to find the perceptual relationships between chords, we conducted factor analysis using Varimax rotation. The ratings of each measure for each chord were averaged across pitch class. Factor analysis extracted twenty-four factors, but any factors with an eigenvalue smaller than 1 were excluded. Four factors remained after this process, and the percentages of variance explained are 41.97%, 26.16%, 14.11%, and 10.32% respectively, which together account for a total of 92.56% of the total variance. Table 3.5. shows variables that are strongly correlated with these four factors. Factor I is highly correlated with relatively dissonant chords—such as augmented and augmented major triads, diminished and half diminished triads, and suspended chords—on the Piano timbre, while dominant chords have a high negative value. Factor II is highly correlated with dissonant and suspended chords on the Organ timbre. Factor III is correlated with major and dominant chords, and, in contrast, major seventh and minor-major seventh chords have large negative values.

Table 3.5.

Chords that are highly correlated with Factors (r > .50)

F1 Dissonance Piano		F2 Dissonance Organ		F3 Major triad		F4 Minor triad	
Aug P	.878	Aug O	.829	Dom P	.768	Minor O	.585
Aug-ma7 O	.639	Aug-ma7 O	.698	Major O	.851	Minor P	.624
Aug-ma7 P	.881	Dim O	.883	Major P	.843	Minor 7 O	-.766
Dim P	.889	Dim7 O	.821	Major 7 O	-.869	Minor 7 P	- .936
Dim7 O	.512	Dom O	.502	Major 7 P	-.967		
Dim7 P	.957	H-dim7 O	.811	Mi-ma7 O	-.895		
Dom O	-.767	Minor O	.649	Mi-ma7P	-.806		
H-dim7 O	.536	Minor7 O	.538				
H-dim7 P	.910						
Mi P	.533						
Sus P	.896						

Factor IV is correlated with minor chords, but minor seventh chords have negative value.

3.6.3. Summary

The results for listeners' ratings reveal the rich variety to the perception of chords in isolation. The rank order for the rating of the four types of triad under consideration is consistent with previous studies (Roberts, 1986: Cook and Fujisawa, 2006: Johnson-Laird et al., 2012). It was also found that triads are not necessarily more consonant, pleasant, stable or relaxed than tetrads: triads and tetrads are spread out evenly across the rank order by rating of each of the 12 types of chord, and chords that share the triads - such as the major triads and the dominant seventh, or augmented triads and the augmented sevenths - tended to have similar ratings. This indicates that the addition of the seventh does not necessarily decrease the consonance or pleasantness level of the chord, but rather that judgements of C/D may rely more on the structure of the triad to which a seventh is added.

In addition to chords, timbre was also an influential factor on participants' judgements. Participants tended to judge organ chords as more dissonant, unpleasant, and tense than piano chords, with this difference in ratings being particularly pronounced in the case of major seventh chords. This result might perhaps be explained by the ambiguous nature of the major seventh chord: on the one hand, it contains within itself the most consonant chord type of all, namely the major triad, while on the other hand, the seventh is commonly considered to be a dissonant interval. Due to this ambiguity, the perceived tension of the major seventh may fluctuate depending on its timbre. Since an organ timbre contains more overtones and reverberation, it may make the chord appear rougher, increasing tension and dissonance, as we will see later.

Listener ratings also varied according to musical expertise. C/D and stability ratings show a wider range for musicians than they do for learners or for non-musicians. This difference was particularly pronounced in the case of chords with either a clearly consonant or a clearly dissonant quality. The difference in ratings between the three groups was relatively large for major triads, dominant sevenths, augmented triads, augmented sevenths, and minor-major sevenths, while the difference was very small for minor chords, minor sevenths, and diminished triads. Finally, an examination of the correlation between the four variables reveals a further difference between the three groups: the musicians were the only group for whom C/D ratings did not correlate with the other three variables, suggesting that listeners with musical training tend to distinguish C/D from stability, pleasantness, relaxation in a way that other listeners do not.

3.7. Three measures and listeners' ratings

In this part, we will compare listeners' ratings and three measures in order to examine how audio descriptors of chords, frequency of occurrence, and listeners' familiarity can explain listeners' perception.

Correlation between roughness and listeners' perception

Figure 3.8. gives the calculated roughness value for all 12 chords, in the keys of C major and F# Major and in both timbres. The calculated roughness value is generally higher for chords played on the Organ, and, with regard to the comparison between triads and tetrads, it can be observed that the existence of the seventh does not increase the roughness value (e.g. the major triad and the major seventh on the Piano are 2.8 and 2.78, respectively). Calculated roughness values are negatively correlated with C/D: $r = -.524$, $df = 46$, $p < .001$, Pleasantness: $r = -.609$, $df = 46$, $p < .001$, Stability: $r = -.446$, $df = 46$, $p = .002$, and Relaxation: $r = -.632$, $df = 46$, $p < .001$,

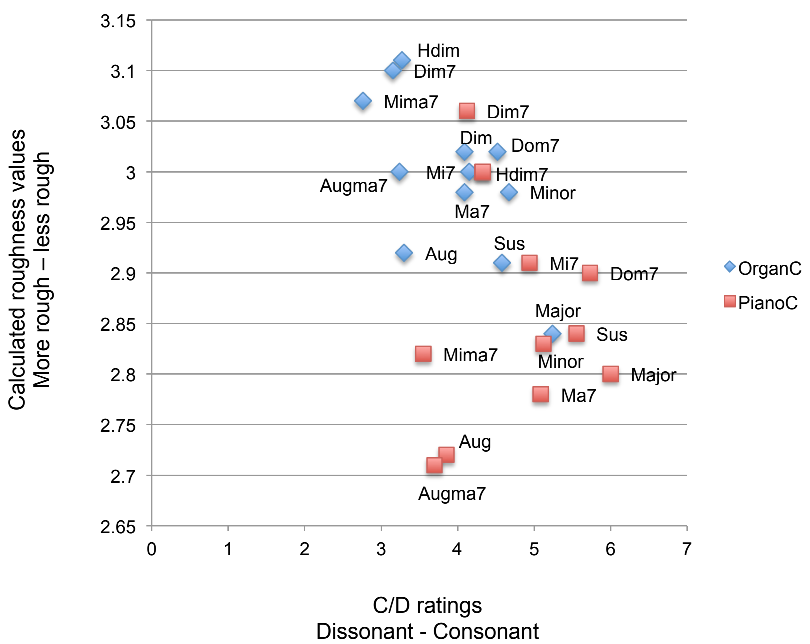

Figure 3.8. C/D ratings (X-axis) and Calculated roughness values (Y-axis) of each type of chords on C

indicating that chords with more roughness were perceived as more dissonant, unpleasant, unstable, and tense. However, the calculated roughness values highlight the inconsistency between the algorithm and listeners' perceptions. Augmented triads in both Organ and Piano have lower roughness values than minor and diminished triads, which contradicts the results from the experiment showing that augmented triads were perceived as more dissonant than both minor and diminished triads.

Correlation between key strength and listeners' perceptions

Additionally, we extracted values of key strength, which indicates the probability of possible candidate keys (Lartillot and Toiviainen, 2007). Key strength can be a good predictor of the perception of chords, since chords that evoke a stronger sense of key are more stable and more consonant (Krumhansl, 1990), and chords with clearer roots are perceived as more consonant (Parncutt, 1988). Key strength values of all twelve

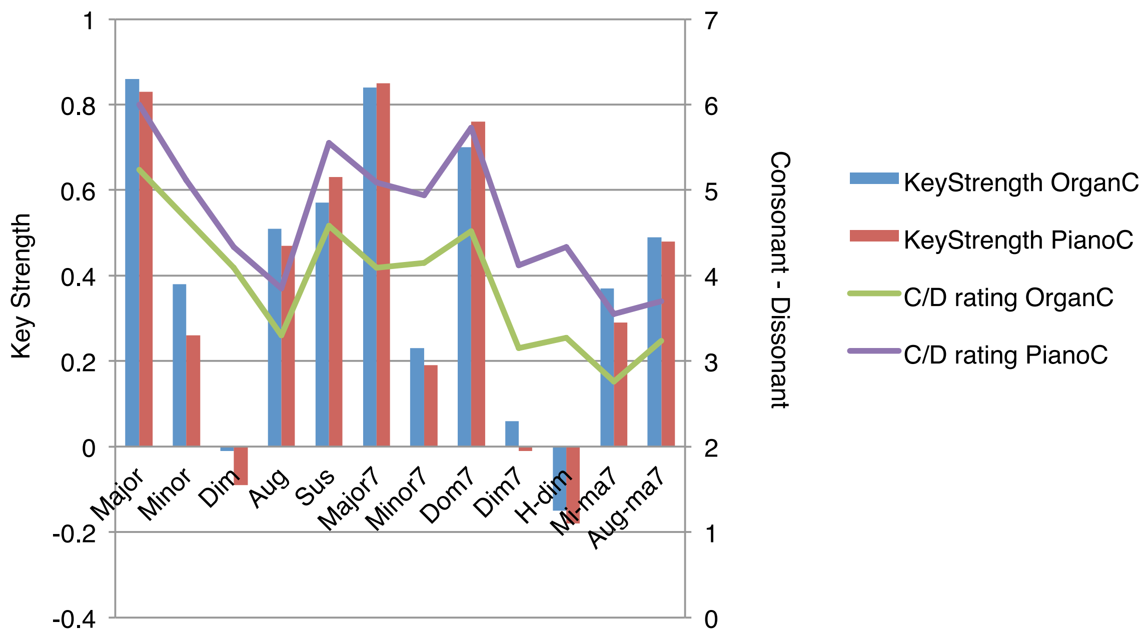

Figure 3.9. Key Strength values for the key of C and C/D ratings for chords on C. The bar graphs show each chord's C major key strength value, and the line graphs show listeners' ratings of the C/D of chords in Piano and Organ timbre.

keys per each chord were calculated, but we picked up the value of the C major key for chords built on C, and the value of the F-sharp major key for chords whose root were F-sharp to assess the correlation with behavioural data. The calculated key strength had a moderate positive correlation with listener ratings on C/D: $r = .373$. $p = .009$, $df = 48$, and with Stability ratings: $r = .386$. $p = .007$, $df = 48$. Figure 3.9 shows the calculated key strength in bars, and C/D ratings in lines. Chords containing the major third and the perfect fifth, such as major triads, major sevenths, and dominant sevenths have higher key strength values, which is consistent with Parncutt's calculations of root ambiguity that major triads and the dominant seventh, respectively, have the clearest roots among triadic and seventh chords. By contrast, chords featuring the diminished fifth, such as diminished triads, diminished sevenths, and half-diminished sevenths, have much lower key strength values than augmented triads. Again, these low calculated values for diminished triads contradict listener perceptions.

The influence of three factors on listeners' perceptions

Three different approaches were used to gather data on variables contributing to the perception of single chords—namely, the 14 extracted acoustic descriptors, the frequency of each chord's occurrence, and listener ratings of timbre familiarity. In order to reduce the number of these variables for Regression Analysis, a Principal Component Analysis was carried out. Principal Component Analysis extracted three components from these variables with an eigenvalue larger than 1, as shown in Table 3.6. The first component seems to be related with timbre, as it is strongly correlated with both familiarity with timbre (organ and piano), and the acoustic features of chords, such as the spectral flux, the spectral centroid, and the spectral flatness. The second component is related to the spectral roughness and the spectral crest. The frequency of the occurrence of chords and key strength, which are knowledge-based variables, influence the third component. These three components will be referred to as *instrumental timbre*, *roughness*, and *chord strength*, respectively.

Table 3.6.

Results of Principal Component Analysis

	PC1	PC2	PC3
Variance explained	62.24%	12.94%	8.47%
Familiarity with timbre	**-.976**	.159	-.018
Spectral flux	**.972**	-.200	.026
Spectral flatness median	**.957**	-.251	.032
Spectral centroid median	**.954**	-.204	.050
Spectral skewness iqr	**-.939**	.231	-.077
Spectral centroid iqr	**.894**	.005	-.027
Spectral flatness iqr	**.885**	-.328	.070
RMS energy envelope iqr	**-.844**	.277	-.182
Spectral skewness median	**-.883**	.042	.049
RMS energy envelope median	**.690**	-.106	-.226
Spectral crest median	**-.688**	**.680**	.072
Spectral regularity	**.614**	**.638**	.100
Spectral roughness	.489	**-.779**	-.053
Spectral crest iqr	-.205	**.735**	.101
Key strength	.080	.257	**.801**
Frequency of occurrence	-.036	-.057	**.899**

Following Principal Component Analysis, a Stepwise Linear Regression was conducted in order to assess the influence of the 14 acoustic descriptions of each chord, timbre familiarity ratings, and frequency of occurrence. Three components – *instrumental timbre*, *roughness*, and *chord strength* – were used as predictors of chord perception ratings, instead of employing only the highest correlating variables of each component as a predictor, as Eerola, Ferrer, and Alluri (2012) did. The results of the linear regression analysis are summarized in Table 3.7. All four ratings were well explained by *instrumental timbre* and *chord strength*, with more than 50% variance explained, but they were not well explained by *roughness*. *Instrumental timbre* correlates negatively with listener ratings for all four variables, which indicates that Consonance, Pleasantness, Stability and Relaxation decrease as factors that are positively correlated with *instrumental timbre* – such as the spectral flux, the spectral flatness, and the spectral centroid – increase. There is a positive correlation, meanwhile, between listener ratings of these four variables and listener familiarity with timbre, the spectral skewness, the RMS energy envelope, and the spectral crest. As for *chord strength*, this also correlates positively with the prediction. This suggests that the more frequently a chord appears and the greater the value of its key strength, the more likely the listener will be to perceive it as consonant, pleasant, stable, and relaxed.

Table 3.7.

Summary of Regression Analysis

Variables	Consonance $R^2_{adj} = .529$			Pleasantness $R^2_{adj} = .649$			Stability $R^2_{adj} = .533$			Relaxation $R^2_{adj} = .645$		
	β	*p*	Partial *r*	β	*p*	Partial *r*	β	*p*	Partial *r*	β	*p*	Partial *r*
Instrumental timbre	- .482	< .001	- .581	- .656	< .001	- .749	- .368	.001	- .482	- .697	< .001	- .767
Roughness	.116	.251	.643	.161	.062	.277	.072	.424	.108	.160	.065	.274
Chord strength	.563	< .001	.643	.484	< .001	.641	.646	< .001	.695	.416	< .001	.581

3.8. General Discussion

This study provides empirical evidence that the frequency of a chord's occurrence contributes to the listener's perception of it. In particular, chords with a higher rate of occurrence tend to be perceived as more consonant: the major triad is the most frequently occurring and the most consonant chord of all the chord types, followed by the dominant seventh and the minor triad. The rank order of frequently occurring chords generally corresponds to their relative C/D: there were no examples of frequently occurring chords with high negative acoustic values, so there was no opportunity for frequency effect to override the influence of acoustic features on chord perception. Krumhansl (1990) demonstrated the effect that the frequency of a chord's occurrence has on its perception, when she compared her experimental data with the frequency of occurrence data of Budge (1943). Krumhansl (1990) and Budge (1943) focussed on diatonic chords I–VII in both major and minor keys: in other words, their focus was on the functions of major, minor and diminished triads in the context of the existing tonal hierarchy, and not on different types of chord. So, it is interesting that, as this study demonstrates, the frequency effect can be observed in different types of chord. Works by Bach and The Beatles, musical giants from the 18th and 20th centuries, were used in our study to establish the presence of the frequency effect (and there is scope for conducting fruitful and interesting further research by taking samples from a wider range of music). This frequency effect inevitably leads to the question of whether a chord sounds consonant because of its frequent occurrence in musical works, or whether a chord occurs frequently because it sounds consonant – the 'chicken or the egg' syndrome. However, our task is not to adjudicate on which came first, but is instead to focus attention on how and why our perception of chords is influenced by the frequency of their occurrence.

Experimental data has also demonstrated the influence of the acoustic features of chords on their perception as predicted. Chords played on the Organ were judged more negatively—in particular for tension—than those played on the Piano. They also had higher values of calculated roughness than Piano chords. This linear relationship between roughness and the perception of tension is consistent with previous studies such as Presnitzer et al. (2000) and Bigand et al. (1996). Also, a negative correlation was found between perceptions of each chord and their roughness value, suggesting that, with the exception of augmented and diminished triads, chords judged to be less consonant, pleasant, stable and relaxed are likely to have a higher roughness value. Previous studies have demonstrated that roughness values for augmented and diminished triads do not correspond with the rank order of their C/D. For instance, Johnson-Laird et al. (2012) calculated that roughness is higher for diminished triads than it is for augmented triads, despite the fact that diminished triads are perceived as being more consonant than augmented triads. Besides triads, the same incongruency between calculated roughness and the rank order of C/D was found in diminished seventh, half-diminished seventh, and augmented-major seventh chords.

However, according to Cousineau et al. (2012), synthetic sound contains more beating than is made by real instruments, and in "real-world sound" beating is not necessarily any more noticeable in dissonant chords than it is in consonant chords. So, we need to bear in mind that beating or roughness may have little effect on C/D judgements of chords that are played by real instruments. In fact, Regression Analysis revealed that the component related to roughness (*roughness*) was not a significant predictor of listeners' ratings of C/D, pleasantness, stability, and relaxation. Instead, the analysis showed that another component, *instrumental timbre*, was a good predictor. Familiarity with timbre is most strongly correlated with *instrumental timbre*, and a greater familiarity with timbre makes a chord seem more consonant, pleasant, stable, and relaxed. Several auditory descriptors are also correlated with this component, showing that a larger difference in spectrum (the spectral flux), in tonal vs. noise balance (the spectral flatness), and in spectral centre (centroid) leads to a more negative perception of chords, while a more symmetrical spectrum (the spectral skewness), a greater range of dynamics (the RMS energy envelope), and a smaller difference between a spectrum's maximum value and its mean (the spectral crest) all contribute to higher chord ratings.

An interesting observation from our experiment is that the presence of the seventh did not increase either the dissonance level of chords or their calculated roughness value, despite seventh chords being considered dissonant in music theory. Some seventh chords, such as major and minor sevenths, were more consonant than augmented and diminished triads, and chords that shared the same triadic base (e.g. the augmented triad and the augmented major seventh; the diminished triad, the half-diminished seventh, and the diminished seventh) were close in the rank order of ratings and tended to be categorised together in Factor Analysis. These results indicate that it is the structure of the triad rather than the presence or absence of the seventh that is the more influential factor in determining a chord's C/D. The results also show that timbre was an important factor in the categorisation of chords, since Factor Analysis revealed that listeners clearly judged dissonant Organ chords differently from the same chords played on the Piano. By contrast, Factors III and IV, which focused on major and minor triads played in both timbres, suggested that timbre had no effect on how these triads were perceived. It may be that the perception of major and minor triads is less influenced by timbre than other chord types on account of them being the most common and hence also the easiest to identify of all chords.

As for the influence of musical training, musicians' ratings of C/D, stability/instability, and tension/relaxation were more varied than the ratings of learners or non-musicians. Musicians perceived consonant chords as more consonant, stable, or relaxed than the other two groups, while they judged dissonant chords as more dissonant, unstable, or tense by comparison. This tendency among musician participants to perceive dissonant chords as more tense than their non-musician counterparts has also been reported by Bigand, et al. (1997) and by Lehdelma and Eerola (2014), indicating the particular sensitivity musicians have with respect to the qualities of different chord types. Musical training makes listeners more discerning with regards to the harmonic relations between tones (McDermott, et al., 2010: Kung, et al., 2014), and it probably also accounts for the wider range of ratings they gave in the present study. Nonetheless, it must be said that this result—that listeners with more musical training perceived dissonant chords as more dissonant—went against our prediction. We had assumed that a greater exposure to dissonance would make listeners perceive dissonant chords as *less* dissonant due to their comparative familiarity; but that was not the case. As Parncutt and Hair (2011) claim, familiarity does not necessarily make a dissonant chord consonant. By way of explanation, perhaps instead of making dissonant chords less dissonant, musical training might strengthen the listener's knowledge about the frequency or otherwise of a given chord's occurrence. Listeners with more musical training know better than listeners with little or no musical training that the minor-major seventh and the augmented-major seventh are rare chords to encounter, and that they are therefore less important and more ambiguous chords. This knowledge, acquired as it is through musical training, might make these chords sound more dissonant to musically trained listeners. The difference between the ratings of listeners with formal musical training, and those of listeners with less or no musical training shows that the C/D of chords is not a purely acoustic phenomenon, but that it also varies according to the listener's musical knowledge and experiences. In contrast to C/D ratings, there was no difference between the pleasantness ratings of the three groups, a result that is in line with previous studies (Johnson-Laird, et al., 2012: Roberts, 1986), and that indicates that musical training is not necessary for the listener to make an aesthetic judgement of a chord.

Differences between musicians and the other two groups were also found by examining correlations between each group's ratings across the four variables. Ratings for consonance, pleasantness, stability, and relaxation were generally positively correlated, indicating that chords perceived as consonant tended to be judged as pleasant (Johnson-Laird, et al., 2012; Roberts, 1986), stable (Bigand & Parncutt, 1997; Bigand, Parncutt & Lerdahl, 1996), and relaxed (Parncutt & Hair, 2011). However, for some listeners, and for musicians in particular, perceptions of consonance did not correlate with perceptions of the other three. This suggests that, for musicians at least, C/D is an independent variable and concept, and thus is not interchangeable with the other variables. Since 'consonance' and 'dissonance' are by origin musical terms—in contrast to the other variables, they are rarely used in non-musical contexts—and since musical training enhances one's sensitivity towards the contributory factors to C/D, perhaps C/D is to some extent a concept and perception that can be acquired, or at least strengthened, through extensive musical training.

One interesting observation from the collective data is that it seems as though C/D and stability were influenced more by participants' musical training and knowledge of tonal hierarchy, whereas pleasantness and relaxation were more influenced by the acoustic features of chords. The finding that musicians were inclined to perceive chords as by turns more consonant and more dissonant, and more stable and more unstable than groups with little or no musical training reflects the fact that a person's perception of C/D and stability is partly attributable to their knowledge of tonal hierarchies, as gained from extensive musical training. A further finding was that calculated Key Strength values for tonic keys only correlated with perceptions of C/D and stability, and not with either pleasantness or relaxation. This suggests that chords that generate a clearer sense of a tonic key have a tendency to be more consonant and stable. This correlation between Key Strength and the perception of C/D and stability also suggests that tonal hierarchy is more closely related to perceptions of C/D and stability than it is to perceptions of pleasantness and relaxation. After all, the notion of Key Strength is based on Krumhansl's (1990) idea that a chord that induces a stronger sense of a key will be perceived as more stable, which is similar to Parncutt's (1988, 1989) theory of "root ambiguity", which affirms that chords with a clearer root tend to be more consonant.

As for pleasantness and relaxation, these variables may be more influenced by acoustic features than by anything else. Calculated roughness values were more negatively correlated with perceptions of pleasantness and relaxation than they were with perceptions of C/D and stability, which means that the greater the roughness value of a chord, the more unpleasant or tense it is perceived to be. Regression Analysis showed that the standard coefficient values of acoustic features were higher for pleasantness and relaxation than for C/D and stability. These findings indicate that acoustic features had a larger influence on perceptions of pleasantness and relaxation than they did on perceptions of C/D and stability.

However, it should be pointed out that the finding that perceptions of stability and tension are influenced, respectively, by one's knowledge of tonal hierarchy and of acoustic features stands in opposition to the findings of previous studies. Previously, it has been reported that there is no difference between musicians and non-musicians in terms of *stability* perception (Bharucha & Krumhansl, 1983; Bigand, 1997), while musicians tended to give higher *tension* ratings to some chords than non-musicians (Bigand et al., 1997; Lehdelma and Eerola, 2014). One possible explanation for this discrepancy is the absence of musical context in the present study. Previous studies (Bharucha & Krumhansl, 1983; Bigand, 1997; Bigand et al., 1997) employed mainly chord or melody sequences with a context as stimuli, in contrast to the chords in isolation used in this study. Meyer (1959) wrote that even a single chord in isolation, without a musical context, is incorporated into and heard within 'the prevalent style of Western music' (p. 46). Still, there may be a difference between the amount of knowledge of tonal hierarchy a single chord can activate compared to the amount that an entire chord progression or melody can activate. It may be the case that chord sequences or melodies with musical context more readily prompt listeners to activate their knowledge of tonal hierarchy than chords in isolation without any context. It would not have been so difficult for listeners to extract the sound features of chords; but it would have been much more difficult for them, especially for those listeners with little or no musical training, to decode the tonal hierarchy information contained within a single chord due to the absence of context. This difficulty in understanding the underlying tonal hierarchy of chords may have led to clearer differences between musicians' and non-musicians' perceptions of C/D and stability, and to an increase in the influence of sound features on the perception of tension.

In summary, this study demonstrates that the frequency of the occurrence of different types of chord is an important contributory factor to their perception, and that musical training is capable of enhancing the listener's knowledge with respect to the frequency of a chord's occurrence. Along with tones and intervals, chords are one of the most fundamental elements in music, and our perception of them is influenced both by their physical acoustic features and by our musical schemata. Which of these factors is considered the more influential depends on which attribute or feature of a given chord one chooses to focus on. It was found that judgements relating to tonal hierarchy (e.g. C/D and stability) vary greatly according to the listener's musical schema, whereas judgements relating to aesthetic quality or emotion (e.g. pleasantness and tension) depend more on a chord's acoustic features and yield results that are more consistent across listeners with differing levels of musical training. The findings also revealed a discrepancy between our relationship with C/D and our relationship with other variables. In particular, the conventional notion that 'consonance accompanies pleasantness' was not always true, especially for listeners with musical training. The findings of this study suggest that our perception of chords is diverse and multidimensional, and our complex and subtle relationship with chords points to the need for varied approaches in future research.

Chapter 4

Musical Contexts and Harmonic Functions

This work is a submission for *Psychomusicology: Music, Mind, and Brain*. Authors: Yuko Arthurs and Renee Timmers

Author contributions

Yuko Arthurs: conducted literature review, made stimuli, conducted experiments, analysed and interpreted the data, prepared figures and tables, and wrote the manuscript.

Dr Renee Timmers: gave counsel at all stages of the work, gave feedback on the manuscript, made suggestions, and helped with revision of the manuscript.

4.1. Introduction

Chapter 3 studied the influence of frequency of occurrence on the perception of single chords. In this chapter, I will focus on the C/D of chords in a musical context. In particular, this chapter examines how the perceived level of consonance and dissonance (C/D) of a chord varies according to whether or not it is heard in a musical context, and how the perceived C/D of a chord varies depending on the type of musical context in which it appears.

As we saw in Chapter 2, when intervals and chords appear within the flow of music, their C/D is called 'musical consonance/dissonance' or 'tonal consonance/dissonance' (Krumhansl, 1990; Terhardt, 1984). According to Lundin (1947), the C/D level of a chord is neither fixed nor absolute, but rather changes according to context. In other words, our perception of C/D depends not just on the sensory features of a chord, but also on the musical context in which that interval or chord is presented. If this is the case, then factors such as: the principles of tonality; the musical context in which the chord appears; the listener's musical schema; the listener's familiarity with the style of music; and the music's acoustic properties may all play a part in shaping C/D perception (Cazden, 1980; Gardner & Pickford, 1943; Krumhansl, 1990; Lundin, 1947; Terhardt, 1984).

As for the influence of musical context, Gardner and Pickford (1943, 1944) conducted experiments in which they employed various chords (details not given) in different contexts and keys as musical stimuli. They found that context did indeed influence participants' judgements of the 'dissonance-level' of target chords. Roberts (1986) also showed that chords sound more consonant when heard in a 'traditional' harmonic progression as opposed to a 'non-traditional' one. Unfortunately, these studies say little about precisely which elements of musical context might be responsible for influencing C/D judgements of chords, and nothing about how they might do so. The influence of context on the evaluation of dissonance was also observed in an experiment by Johnson-Laird et al. (2012), in which major triads, sevenths, minor sevenths, and minor triads were judged to be more consonant when heard in the context of a common harmonic progression than when in random, non-tonal sequences. All of these studies show that the C/D level of intervals and chords are not fixed. I choose to refer to this phenomenon as the 'fluidity' of C/D, as C/D levels are apt to change depending on context. It is certainly the case that each chord has a level of C/D based solely on its sensory C/D. However, the effects of musical context and of the listener's musical schema mean that, for all chords, there is fluidity to C/D judgements.

4.2. Present study

The purpose of the present study is to investigate the influence of musical context, and in particular the influence of harmonic function, on the listener's C/D and P/U perceptions of a triad. Experiment 3 tested listener's C/D perceptions of major, minor, augmented, and diminished triads in isolation. In Experiment 4, all triads were allocated a different position in the short sequence IV-V-I in both major and minor keys (Figure 4.1.). The results of the two experiments will be compared in order to assess the 'fluidity' of the chords – that is, the extent to which the level of each chord's C/D varies according to whether it appears in isolation or in a musical context.

Although musical context is considered to be the key factor in determining musical C/D, it has not been clearly specified what 'musical context' connotes, nor what or how the various components of musical context influence C/D judgements. In the case of a short harmonic progression consisting of several chords, musical context can be defined as the relationship between the target chord, and the preceding and succeeding chords. For short harmonic progressions, then, sensory relatedness and the hierarchy between notes and chords in a local context, and the function of chords in a global context, together comprise the musical context. In the case of longer, more complicated musical works, melodic anchor and rhythmic patterns will be part of the musical context as well. This study considers musical context in two ways: a musical context in which the same chords are given different harmonic functions; and the presence and absence of musical context - that is, chords in isolation and chords that appear in some musical context. Experiment 4 examines the fluidity that results from the same chord being heard in different functions, and later the results of Experiments 3 and 4 will be compared in order to analyse whether and to what extent context influences fluidity – that is to say, how the C/D of chords varies according to whether they are heard in a musical context.

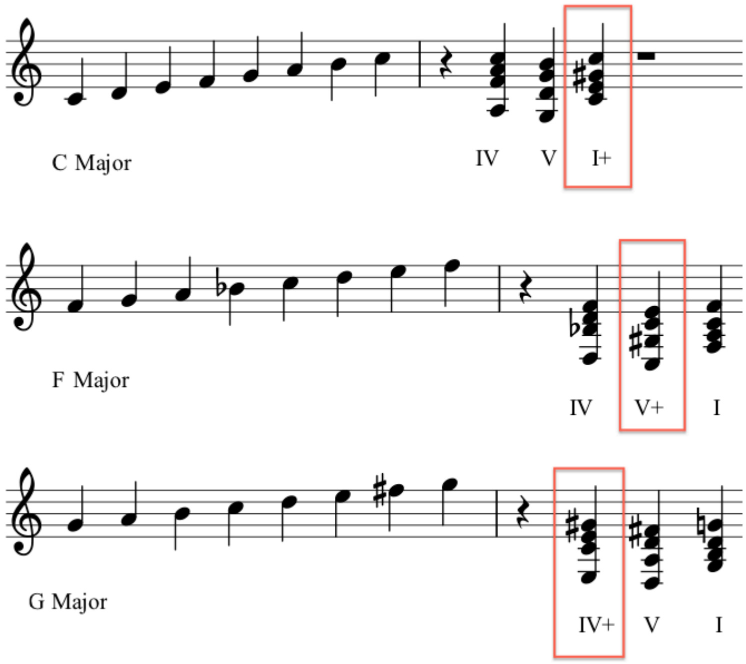

Figure 4.1. Stimuli sequence for Experiment 4.

The chords in boxes are the target chords. All four types of target chord (major, minor, augmented and diminished triads) were allocated a different position in the sequence IV-V-I. The harmonic function of the target chord and the key of the sequence vary depending on the target chord's position.

4.3. Hypotheses

Fluidity 1. different harmonic functions

In Experiment 4, each triad was allocated a different position in the short sequence IV-V-I in both major and minor keys (major and minor triads appeared only in sequences in major or minor keys respectively). The appearance of an augmented or diminished chord is expected in certain progressions, since both chords have certain 'expected' harmonic functions. In such cases, the chord will be more familiar and therefore less dissonant-sounding than the same chord in an aberrant or unfamiliar chord progression, or if it occupies an unfamiliar function. There are three possible models for explaining how augmented and diminished chords may be perceived differently depending on harmonic function: the familiar harmonic function model; the tonal stability model; and the position of the fifth note of the target chord model.

1. **The Familiar Harmonic Function Model**

Previous studies (Koelsch, Gunter, Friederici, & Schroeger, 2000; Leino, Brattico, Tervaniemi, & Vuust, 2007; Loui, Grent-'t-Jong, Torpey, & Woldorff, 2005; Maess, Koelsch, Gunter, & Friederici, 2001) show that the degree of expectation for a chord varies according to its harmonic functions. In other words, chords are expected in a certain context with a certain harmonic function, but the acoustically identical chord can seem unexpected when it performs an uncommon harmonic function. These studies used ERPs, and demonstrated that the Neapolitan chord elicits a larger amplitude of the ERAN when it appears on the unexpected tonic function than when on the expected subdominant function (Koelsch et al, 2000; Leino et al, 2007; Loui et al, 2005; Maess et al, 2001). On the basis of this, the familiar harmonic function model predicts the following: augmented and diminished chords will sound most consonant when performing their most familiar and conventional functions. In music theory, augmented chords appear in a minor key as the mediant (Piston, 1950), though in practice the mediant is quite an uncommon chord. Augmented chords are often used as a substitute for a dominant chord, or as neighbouring or passing chords (for example, within the progressions I – I+ - IV, and I –I +- I), in order to give the music a chromatic sound and to embellish the harmony (Gauldin, 1997). The most familiar function for augmented triads is the dominant, followed by the tonic. Diminished triads can act as leading note chords that precede the tonic and the end of the cadence, and have a dominant function in this context. They can also appear as the supertonic in a minor key (Andrews, 1950), and in this context they have a subdominant function. This familiar harmonic function model predicts that augmented chords will sound more consonant when they appear on the dominant or tonic, and that diminished chords will be more consonant when on the dominant or subdominant. Conversely, they should sound most dissonant when occurring in any other function.

2. The Tonal Stability Model

Turning now to the second model, which is based on the notion of the tonal hierarchy of chords, and according to which C/D and P/U judgements are susceptible to the influence of the tonal stability of chords rather than being determined by the familiarity of their function. The second model supposes that an unexpected chord sounds more dissonant when it appears on a more stable function than when on a less stable function, because the violation of stability will be greater with the former. This idea is based on the theory of the psychological tonal hierarchy and stability of chords (Bharucha & Krumhansl, 1983; Krumhansl, 1990). In Western tonal music, there are 12 tones in each octave, and chords can be built up on each tone. However, these 12 tones or chords do not appear an equal number of times in most pieces of music, but rather some tones and chords - such as tonic, dominant, and subdominant - occur more frequently than others. These dominating tones and chords are more important, and are described as stable because they help to establish the sense of key and function as a cognitive reference (Bharucha & Krumhansl, 1983; Krumhansl, 1990). A series of studies by

Krumhansl employing the probe-tone technique demonstrate the psychological tonal hierarchy that exists in a listener's musical schema. Her studies reveal that listeners give the highest ratings of fitness to tonic tones (Krumhansl & Kessler, 1982) or chords (Krumhansl, 1990), followed by dominant and subdominant tones or chords. Bigand (1997) also provides empirical evidence of a correlation between the level of a tone in a tonal hierarchy and that tone's stability. This psychological tonal hierarchy is generally in accordance with music theory, and with findings concerning the frequency of a chord's occurrence as investigated by Budge (1943). Chords rooted in a tonic tone (e.g., C-E-G, C-E-G-B in the key of C major) account for 41.79% of the musical pieces she examined, followed by 31.68% for chords with a dominant tone root, and 8.45% for chords with a subdominant tone root (Krumhansl, 1990). Tonic tones or chords are the most frequently occurring, and are therefore the most stable in the hierarchy. This dominance of the tonic can be represented by other subjective measures (Tillmann, 2008). Of all chords, tonic chords elicit the greatest sense of completion (Tillman & Lebrun-Guillaud, 2006), and the lowest levels of tension (Bigand, Parncutt, & Ledhal, 1996). Tones and chords with more stability are processed more quickly and accurately (Bigand, Tillmann, Poulin-Charronnat, & Manderlier, 2005; Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003; Tillmann, & Marmel, 2013), and judgements of C/D are processed most quickly when the target chord is on the tonic, followed by the dominant, and most slowly when on the subdominant (Bigand & Pineau, 1997; Tillmann, Janata, Birk, & Bharucha, 2008).

Stability is also attributable to the sensory C/D of chords (Bigand et al., 1996; Dibben, 1999), and roughness especially is an important contributory factor. Chords with more roughness induce higher musical tension (and less stability) than those with less roughness (Bigand et al., 1996), and musical tension is often considered the opposite of resolution or stability (Krumhansl, 1990). Chords containing the perfect fifth have relatively simple frequency ratios and are therefore judged as being stable and consonant, even in atonal music (Dibben, 1999). There is a correlation between sensory C/D and stability: the more consonant a sound is, the more stable it sounds to the listener. Therefore, being consonant is a prerequisite for tonal stability.

The second model supposes that an unexpected chord, one that does not normally appear in that context, will violate tonal stability. The violation of tonal stability may be bigger when the chord occurs on a more stable function than when it occurs on a less stable function. Thus, an unexpected chord on the tonic is likely to sound particularly dissonant because of the violation of tonal stability, while a similar chord on the subdominant function will be less so due to it being less of a violation of stability.

3. The Position of the Fifth Note Model

The third model to consider is one that was originated during the course of this study, and it concerns the position of the fifth note of the target chord in the context of the scale. The model predicts that the C/D of augmented and diminished chords may be influenced by the importance of the fifth tone of the chord, which is replaced by an augmented or diminished tone. In Experiment 4, the same target chords are allocated to one of three unexpected positions in a short harmonic progression, IV-V-I. For example, an augmented chord, C- E-G# appears on IV when the sequence is in the key of G major, on V when it is in the key of F major, and on I when it is in the key of C major (See Figure 4.1). An acoustically identical chord can appear in different keys, and can as a consequence perform different harmonic functions. In addition, the position of a chord's constituent tones in the tonal hierarchy will change depending on the key. These facts indicate that the tonal hierarchy is dependent on context rather than on the acoustic sonority of a chord (Bigand, 1997; Tillmann, 2008).

Table 4.1

Summary of Fluidity 1 hypotheses.

	Hypothesis					
	Familiarity		Stability of function		Position of the fifth	
	Augmented	Diminished	Augmented	Diminished	Augmented	Diminished
expected /consonant	Tonic Dominant	Dominant	Subdominant Dominant	Subdominant Dominant	Dominant Tonic	Dominant Tonic
unexpected /dissonant	Subdominant	Tonic Subdominant	Tonic	Tonic	Subdominant	Subdominant

To illustrate this further, the fifth note of a C major chord, G, is a dominant tone when in the key of C major; but it becomes a supertonic when in the key of F major, and so its

importance in the hierarchy changes accordingly. In augmented and diminished chords, however, the fifth note (G sharp and G flat respectively when the root is C) does not feature either in the C major scale or the C minor scale, and this deviation violates the listener's expectations. On this basis, the third model hypothesises that a chord whose fifth note is replaced and violated by an augmented or diminished note will be more dissonant when the replaced tone has a more important position in the tonal hierarchy, because the violation of expectation will be greater in such a case. The fifth note of a chord will be the tonic when that chord is on IV, or the supertonic when on V, or the dominant when on I - so the prediction is that unexpected augmented and diminished chords will sound most dissonant when they are on the subdominant (IV) followed by when they are on tonic (I), and most consonant when on the dominant (V).

Table 4.1 summarises the three hypotheses regarding the effect on C/D of the function of a chord. The first hypothesis predicts that a chord will sound more consonant when it appears on the most frequent, and therefore most familiar, function. Augmented chords are thus expected to be more consonant when on the tonic or dominant, and less consonant on the subdominant. Diminished chords, meanwhile, may sound most consonant when heard on the dominant, and less consonant when on any other functions. The second model supposes that augmented and diminished chords will sound most dissonant when they occur on the tonic because of the greater violation of stability that this would represent. The third model posits that the C/D of augmented and diminished chords is influenced by the importance of the fifth note of chords in a key context: a chord will sound more dissonant when the fifth note of the chord being replaced by either an augmented or diminished tone has a more important position in a tonal hierarchy. According to this model, both augmented and diminished chords are most consonant when they appear on the dominant, followed by the tonic, and the least consonant when on the subdominant. Note that the second and third models consider different aspects of the tonal hierarchy. The second model concerns the stability of the function performed by the chord, while the third model deals with the importance of the fifth tone of augmented or diminished chords in a key context.

Fluidity 2. The presence and absence of a musical context

The C/D ratings for four types of chord in Experiment 3 (without context) and the ratings for Experiment 4 (with context) will be compared in order to examine the second variety of fluidity: the influence of context on the C/D level of a chord. Expectedness may play an important role in shaping the influence of context on C/D perception. Studies by Roberts (1986) and Johnson-Laird, Kang, and Leong (2012) found that chords were judged to be more consonant when appearing in more orthodox, expected contexts. In terms of the present study, then, we can expect that the same chord will sound more consonant when appearing in a more expected musical context than when heard in isolation, and it will sound more dissonant in unexpected musical contexts than in isolation. By contrast, the C/D level of a chord in isolation can only be influenced by its acoustic features as it is not subject to the effects of context and expectedness.

The influence of context is expected to vary according to the type of chord in question. The C/D level of augmented and diminished chords both with and without context is expected to vary more than the C/D level of major and minor triads. This is because augmented and diminished triads are less stable (Krumhansl, 1990), and have less clear roots than major and minor triads (Parncutt, 1988). Also, unlike both major and minor triads (e. g. C-E-G and C-E♭-G), the augmented (e.g., C-E-G#) and diminished (e.g., C-E♭-G♭) triads used in this study are not comprised solely of tones from the key scale, and neither can they be tonic chords of the key. These factors help to contribute to the wider range of C/D judgements that these chords elicit compared to major and minor chords.

4.4. Experiment 3. Chords Without Musical Context

4.4.1. Method

Participants

Thirty-six adults (Male: 16, Female: 20. Age range: 21-74 years, with a mean age of 33.72 years), all with a moderate amount of musical experience, were recruited. There were 18 participants who had had at least 5 years' worth of music lessons in some form or other, while a further 11 participants were either music students or had already gained degrees in music. 7 participants had not received any formal music lessons or training, but played an instrument or listened to music on a daily basis.

Materials

Materials consisted of major, minor, augmented and diminished triads built on 12 scale degrees (C4: 261.63 Hz, C#4, D4, D#4, E4, F4, F#4, G4, G#4, A4, A#4, B4: 493.88 Hz), all of which were played in root and close position, making a total of 48 triads. Each triad was created by a software program called Cubase using a piano sound, YAMAHA S90ES Piano. The duration of each chord was 1.10 seconds.

Procedure

Forty-eight single triads in root position and close position, each one either a major, minor, augmented or diminished triad, were played in a random sequence using all 12 keys. Participants were asked to judge whether each chord was either consonant or dissonant by pressing buttons on a computer keyboard as quickly and accurately as possible. The next chord would appear after the participant had pressed the 'continue' button. Participants' response times were recorded.

4.4.2. Results and discussion

Table 4.2 shows the median, 25th and 75th percentiles of C/D judgements for each chord. As can be seen, major triads were judged the most consonant type of triad, followed by minor triads, and then diminished triads, while augmented triads were considered the most dissonant triad. This result reconfirms those of similar experiments in the past (Bidelman & Krishnan, 2011; Cook & Fujisawa, 2006; Johnson-Laird et al., 2012; Roberts, 1986), and contradicts the rank order of calculated dissonance value by Hutchinson and Knopff (1979). Friedman's non-parametric test was used to compare the frequency of 'Consonant' responses for each chord, averaged across 12 keys per participant as the data was not normally distributed. The results show that there are statistically significant differences between listeners' judgements of each chord type, $\chi^2 = 75.47$, $df = 3$, $p < .001$. The Wilcoxon sign-ranked test shows that judgements for major triads were significantly higher – that is to say, participants judged them to be significantly more consonant - than for minor triads, $z = -3.40$, $n = 36$, $p < .001$, two-sided, augmented triads, $z = -5.17$, $n = 36$, $p < .001$, two-sided, and diminished triads, $z = -4.74$, $n = 36$, $p < .001$, two-sided. As for minor triads, judgements were significantly higher than for either augmented triads, $z = -5.04$, $n = 36$, $p < .001$, two-sided, or diminished triads, $z = -3.96$, $n = 36$, $p < .001$, two-sided. Wilcoxon sign-ranked test also shows that judgements for diminished triads were higher than for augmented triads, $z = -4.36$, $n = 36$, $p < .001$, two-sided.

Reaction time (the length of time between the start of the sound stimulus and the participant's response) was analysed using a one-way ANOVA for Repeated Measures (Chord Type) after log-transformation. However, no main effect of Chord Type on response time was found ($p = .884$).

Table 4.2

The median, 25th and 75th percentiles of C/D judgements of each chord in isolation

	25th percentile	Median	75th percentile
Major	.687	.958	1.00
Minor	.437	.708	.916
Augmented	.000	.083	.416
Diminished	.250	.416	.729

4.5. Experiment 4. Chords with musical context

Experiment 4 examined differences in the perception of the same four triads from Experiment 3 (major, minor, augmented and diminished triads) when these are given different harmonic functions. All triads were allocated a variety of different positions in the short sequence IV-V-I in both major and minor keys (major and minor triads appeared only in sequences in major or minor keys respectively).

4.5.1. Method

Participants

The participants were the same individuals who took part in the previous experiment.

Materials

We used 72 chord sequences. Each chord sequence was preceded by a diatonic scale in order to present the key to the participant, and was then followed by the following three chords: IV-V–I (See Figure 4.1). One of the chords was the target chord. Triadic chords with roots of C, F♯, A, or E♭ - these being the most distant tones in the circle of the fifths - were chosen as target chords to cover all 24 keys (Table 4.3). For example, a C major target chord is capable of fitting into three different keys depending on its function: the key of C major when on the final tonic chord (I) of the sequence IV-V-I; the key of F major when on the dominant (V); and the key of G major when on the subdominant (IV). Thus, it is possible to create sequences in all 24 keys using triads built on only on the roots of C, F#, A, and E♭. All chord sequences contained either one augmented triad (24 sequences), or one diminished triad (24 sequences), or a major or minor control triad (24 sequences). Target chords were put in either the tonic, the dominant or the subdominant position in each chord sequence (Figure 4.1). It is true that, in normal harmony practice, augmented or diminished chords do not

Table 4.3 *Target chords, harmonic functions and the key of sequences*

Chord and the root/ Function	G(#/♭) E(♭) **C**	C(#/##) A (#) **F#**	E (#/♭) C (#) **A**	B (♭/♭♭) G (♭) **E ♭**
Tonic	C major/minor key	F# major/minor key	A major/minor key	E♭ major/minor key
Dominant	F major/minor key	B major/minor key	D major/minor key	A♭ major/minor key
Subdominant	G major/minor key	D♭ major/minor key	E major/minor key	B♭ major/minor key

appear in the cadence IV-V-I. Nonetheless, the rationale behind intentionally allocating them to the IV-V-I sequence was that we would be able to see the effect of function more clearly.

All sound materials were sourced from Cubase, and a piano sound, YAMAHA S90ES Piano was used. The duration of each sequence was approximately 7 seconds in total: the scale was 2.20 seconds, and the first chord appeared after 0.85 seconds of silence. Each chord was 1 second long, and there was 0.50 seconds' silence between them. The interonset interval was 1.50 seconds. The aim was to present a sequence that allowed participants enough time to judge each chord, but that was not so slow that they would have trouble perceiving the three chords as a cadence. The tempo and loudness of all materials were kept constant throughout.

Procedure

Seventy-two chord sequences consisting of a scale and three chords were presented. Two tasks were given to participants: to give C/D ratings for each individual chord within the chord sequence, and to give C/D and pleasantness ratings for the entire chord sequence. The first task for participants was to judge whether each of the three chords they heard was either consonant or dissonant as quickly and accurately as possible, which they did by pressing a button directly after each chord was played. One of these three chords was either augmented or diminished (target chords), or a control chord (major or minor). Participants were not informed prior to hearing which of the chords would be the target chord. The chords in the sequence appeared successively and the listener was not able to pause the sequence, meaning that they had to respond before the next chord. The second task was that, after each sequence had finished, participants rated the C/D and P/U levels of the whole sequence on a 7-point scale, with 1 being extremely dissonant/unpleasant and 7 being extremely consonant/pleasant.

Design

Combining the manipulation of Mode (two levels: major and minor), Chord Type (three levels: augmented triads, diminished triads, and controls), and Functions (three levels: tonic, dominant, and subdominant) results in a possible 18 conditions for the four target chords. There are 72 sequences in total. In the analysis, responses were averaged across the different pitches that were used, resulting in 18 responses per participant.

4.5.2. Results and discussion

C/D judgments of the target chords

Listeners' judgements of the target chords as being either 'Consonant' or 'Dissonant' were recoded as 0 or 1, respectively. The frequency of each response was averaged across the keys per 18 conditions, and the resulting data was not normally distributed. Hence, a non-parametric test was performed to examine the influence of three factors - Mode, Chord Type, and Function - on C/D judgements, and their interactions with each other. The Wilcoxon signed rank test showed no statistically significant differences between major and minor modes. As for Chord Type, Friedman's two-way analysis of variance by ranks revealed significant differences in C/D judgements depending on Chord Type, $\chi^2 = 59.61$, $df = 2$, $p = .001$. Post-hoc analysis with the Wilcoxon signed-rank test was conducted with a

Bonferroni correction applied. As a result, the alpha level for statistical significance was set at $\alpha = .017$. No significant difference in C/D judgements between augmented and diminished triads was found. However, there were significant differences between augmented and control triads (major and minor triads), $z = 5.19$, $n = 36$, $p < .001$, and between diminished and control triads, $z = 5.17$, $n = 36$, $p < .001$. These results indicate that the control triads were more consonant than either augmented or diminished triads. An application of Friedman's test also revealed statistically significant differences between tonic, dominant, and subdominant, $\chi^2 = 7.32$, $df = 2$, $p = .026$, and post-hoc analysis with the Wilcoxon signed-rank test showed that the subdominant was more consonant than the dominant, $z = 2.46$, $n = 36$, $p = .0014$, though there was no difference between either the tonic and the dominant, or the tonic and the subdominant. In terms of the interaction between Chord Type and Function, no significant difference was found in either augmented or control triads (major and minor triads). There were statistically significant differences in C/D judgements for diminished triads depending on Function, $\chi^2 = 18.43$, $df = 2$, $p < .001$, with diminished triads on the subdominant judged to be more consonant than those on either the tonic, $z = 3.18$, $n = 36$, $p = .001$, or the dominant, $z = 3.33$, $n = 36$, $p = .001$. As for the triple interaction between Mode, Chord Type and Function, the application of Friedman's test in augmented and control triads showed no significant difference between Mode and Function. However, there were significant differences in diminished triads both in major modes, $\chi^2 = 12.80$, $df = 2$, $p = .002$, and minor modes, $\chi^2 = 15.50$, $df = 2$, $p < .001$. Post-hoc tests revealed that C/D judgements for diminished triads in major modes on the subdominant were higher than those on either the tonic, $z = 2.56$, $n = 36$, $p = .010$, or the dominant, $z = 2.51$, $n = 36$, $p = .012$. Equally, in minor modes, diminished triads on the subdominant were more consonant than those on either the tonic, $z = 2.73$, $n = 36$, $p = .006$, or the dominant, $z = 3.08$, $n = 36$, $p = .002$. The results reveal the strong tendency among participants to perceive diminished triads as being more consonant when on the subdominant.

Participants' reaction times were also analysed after log-transformation. A three-way repeated measures ANOVA indicated a significant main effect of Function: $F(1.68, 59.02) = 14.720$, $p < .001$, partial $\eta^2 = .29$. Participants responded quickest to chords on the dominant ($p < .001$), followed by those on the tonic, and lastly on the subdominant.

Overall consonant/dissonant ratings

After listening, participants rated C/D and pleasantness levels. A three-way ANOVA with repeated measures was performed to test the effect of Mode (major vs. minor), Chord Type (augmented, diminished, and control), and Function (tonic, dominant, subdominant) on ratings and reaction times. There was a significant main effect of Mode: $F(1, 35) = 11.29$, $p = .002$, partial $\eta^2 = .24$, as sequences in major keys were rated more highly (in other words, were considered more consonant) than those in minor keys. Sequences containing only major and minor triads were rated higher than those containing augmented or diminished triads ($p < .001$); Chord Type: $F(1.24, 43.39) = 155.21$, $p < .001$, partial $\eta^2 = .81$. There was a significant interaction between Mode and Chord Type: $F(2, 70) = 12.52$, $p < .001$, partial $\eta^2 = .26$ (Figure 4.2). As for the effect of Function, this had a significant main effect: $F(2, 70) = 15.50$, $p < .001$, partial $\eta^2 = .30$. There was significant interaction between Chord Type and Function: $F(3.32, 116.19) = 15.11$, $p < .001$, partial $\eta^2 = .30$. The mean ratings are shown in Figure 4.3. Sequences containing augmented triads on the tonic in a major context were rated significantly lower (more dissonant) than those on other functions ($p < .001$), while sequences containing diminished triads on the subdominant in both major and minor contexts were significantly more consonant than those on either the tonic or dominant ($p < .001$), replicating the results of the evaluations of specific target chords reported above.

As for the log-transformed reaction times for C/D ratings, there was a significant main effect of Chord Type: $F(2, 70) = 18.565$, $p < .001$, partial $\eta^2 = .33$. Sequences that contained control chords as targets (major and minor triads) were rated quickest among the three types of chord, and significantly quicker than diminished chords ($p < .001$). An interaction between Mode and Chord Type was also found: $F(2, 70) = 9.04$, $p < .001$, partial $\eta^2 = .20$: the effect of Chord Type varied according to Mode. Control chords in a major context (all of which were major triads) were processed significantly quicker than were augmented and diminished triads ($p < . 001$), although there was no difference in reaction times between sequences containing minor, augmented or diminished triads.

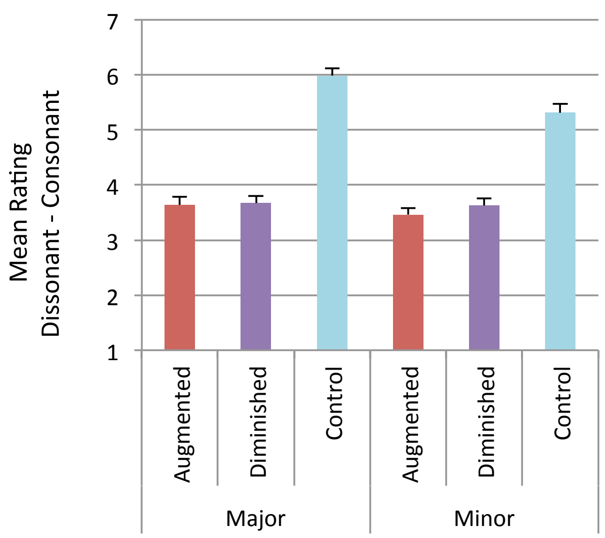

Figure 4.2. Mean ratings of overall C/D judgements for Mode and Chord Type

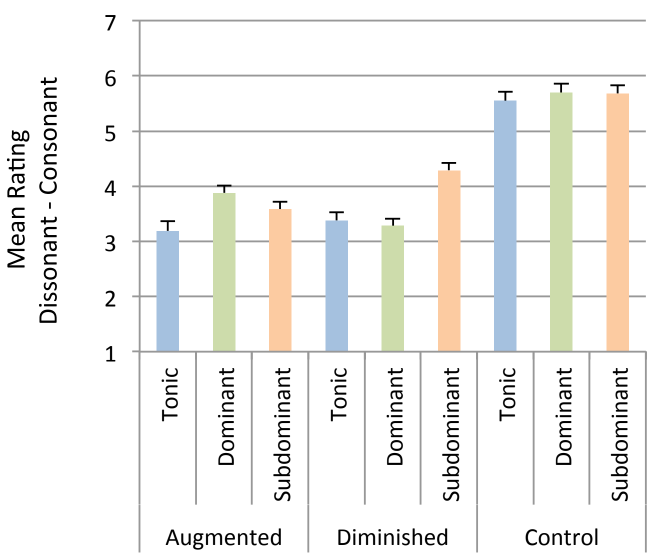

Figure 4.3. Mean ratings of overall C/D judgements for Chord Type and Function

Overall pleasantness ratings

A three-way ANOVA with repeated measures (Mode 2, Chord Type 3, Function 3) was performed on the P/U ratings. All main effects were found to be significant: Mode: $F(1, 35) = 4.51$, $p = .041$, partial $\eta^2 = .11$, Chord Type: $F(1.21, 42.62) = 88.37$, $p < .001$, partial $\eta^2 = .71$, Function: $F(2, 70) = 17.51$, $p < .001$, partial $\eta^2 = .33$. The general trend was very similar to that for overall C/D ratings. There were significant interactions between Mode and Chord Type: $F(2, 70) = 11.22$, $p < .001$, partial $\eta^2 = .24$ (Figure 4.4), and between Chord Type and Function: $F(4, 140) = 18.072$, $p < .001$, partial $\eta^2 = .34$ (Figure 4.5). The effect of Chord Type varied according to Function, as sequences featuring augmented triads on the tonic were significantly different from those with the same triads on the dominant and subdominant: $F(1, 35) = 17.13$, $p < .001$, partial $\eta^2 = .32$. Also, the sequences with diminished triads on the subdominant were judged more pleasant than those with diminished triads on either the tonic or the dominant: $F(1, 35) = 38.96$, $p < .001$, partial $\eta^2 = .51$.

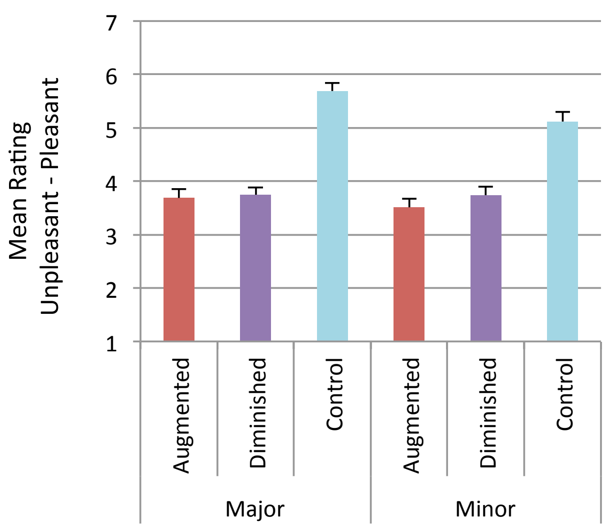

Figure 4.4. Mean ratings for overall pleasantness of Mode and Function

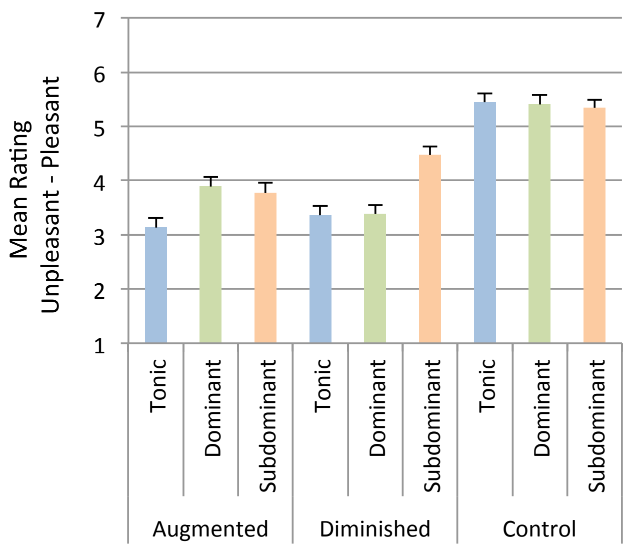

Figure 4.5. Mean ratings for overall pleasantness of Chord Type and Function

As for log-transformed reaction times, only a significant main effect of Chord Type was found: $F(2, 70) = 13.23$, $p < .001$, partial $\eta^2 = .27$. Responses for control chords were quickest among the three types of chord, and were significantly quicker than responses for augmented triads ($p < .001$).

Correlation between C/D and P/U

The results of the three-way ANOVA with repeated measures, one for each overall C/D and P/U evaluation, indicate that both have identical main effects (Mode, Chord Type, and Function) and interactions (Mode and Chord Type, and Chord Type and Function). Pearson's product-moment coefficient revealed a very strong positive correlation between the mean evaluation of C/D and P/U: $r(18) = .99$, $p < .001$. Additionally, the data we assessed on the correlation between participants' C/D and P/U ratings revealed interesting individual differences. In short, not all participants gave similar ratings to C/D and P/U. The range of coefficient values run from -.092 to .980, with the median being .831. For most participants, C/D and P/U ratings were highly correlated ($p = .001$ to $p = .015$). However, for a few participants (four out of 36), C/D and P/U were evidently different qualities, demonstrated by the fact that their results show no correlation between C/D and P/U ($r < .50$, $p > .05$). Nevertheless, C/D and P/U ratings are generally very similar overall, and it can be supposed that most participants perceived them similarly. This supposition is also consistent with the findings of Guthrie and Morrill (1928), who noted that judgments of the consonance and pleasantness of intervals were very similar.

Chords without and with musical context

A non-parametric test compared the C/D judgments of chords in isolation (Experiment 3) with those of chords in context (task 1 in Experiment 4, target chords), in order to see how judgments differ between chords without and with musical context. The Wilcoxon Signed

Rank test was performed to compare eighteen pairs (two Modes, three Chord Types, and three Functions) with a Bonferroni correction applied, resulting in an alpha level for statistical significance that was set at $\alpha = .00278$. The results for significant pairs are shown in Table 4.4. There was no statistically significant difference between control triads, with the exception of minor triads on the subdominant, which were more consonant than when in isolation, $z = 3.29$, $n = 36$, $p = .001$. As for augmented and diminished triads, all were significantly different, except for augmented triads on the dominant in both major and minor modes. For most of the pairs, the results were positive: that is, chords were more consonant when appearing in context than when in isolation. However, the results for diminished triads indicate that diminished chords on the dominant in both major and minor modes were judged more dissonant when heard in context.

Table 4.4. *The significant results of Wilcoxon signed rank test for C/D judgement in isolation (Experiment 3) and in a musical context (Experiment 4)*

Function/		Tonic		Dominant		Subdominant	
Chord	Mode	z ratio	*p*-value	z ratio	*p*-value	z ratio	*p*-value
Aug	Major	**4.84**	**< .001**	-2.87	.004	**5.26**	**< .001**
	Minor	**5.09**	**< .001**	-2.41	.016	**4.76**	**< .001**
Dim	Major	**4.49**	**< .001**	**-4.80**	**< .001**	**4.14**	**< .001**
	Minor	**4.06**	**< .001**	**-4.61**	**< .001**	**4.70**	**< .001**
Minor	Minor	2.90	.004	2.23	.026	**3.29**	**.001**

4.6. General discussion

Two experiments were conducted to investigate the influence of musical context on the C/D perceptions of four triads. In Experiment 3, participants were presented with four types of triad without musical context, and they were asked to judge whether these were consonant or dissonant. Major triads were judged the most consonant, followed by minor, and then by diminished. Augmented triads were judged the most dissonant. This result is consistent with previous studies such as Bidelman & Krishnan (2011), Cook & Fujisawa (2006), Johnson-Laird et al. (2012), and Roberts (1986).

Experiment 4 investigated the influence of context and function on the C/D and P/U levels of chords. Participants judged whether each chord of the three-chord sequences they were played was either consonant or dissonant (task 1), and rated C/D and P/U levels of the whole sequences (task 2). Across all tasks, the control chords (major and minor triads) were rated higher for consonance and pleasantness than either augmented and diminished chords. Major chords were in addition rated higher for consonance and pleasantness than minor chords, and were judged most quickly, corroborating the results of similar experiments that have demonstrated that more expected stimuli are processed more quickly (Bigand et al., 1999; Bigand & Pineau, 1997; Tillmann et al, 2008; Tillmann & Lebrun-Guillaud, 2006).

Fluidity 1: Different harmonic functions

The familiarity model predicts that a chord will sound more consonant when it is heard on a more familiar harmonic function. Since, for example, the dominant or tonic is a familiar function for augmented chords, and the dominant or subdominant are familiar functions for diminished chords, the familiarity model will predict that these chords will sound more consonant than the same chords on a less familiar function. By contrast, the tonal stability model predicts that augmented or diminished chords will be most dissonant when on the tonic, followed by the dominant, and most consonant when on the subdominant. The third model based on the position of the fifth note in a scale predicts that the target chord will sound most consonant on the subdominant, followed by the tonic, and most dissonant when on the dominant. This prediction derives from the idea that a chord is more dissonant when its fifth note, which is violated by an augmented or diminished tone, has more importance in tonal hierarchy

The results of Experiment 4 show that the C/D levels of acoustically identical chords vary according to harmonic function, a finding that closely matches the previously mentioned hypothesis that the same chord will provoke different expectations and brain responses when it fulfils different harmonic functions (Koelsch et al., 2000; Leino et al., 2007; Loui et al., 2005; Maess et al., 2001). The difference between functions was very clear in the case of diminished chords in both major and minor contexts. Both judgements for target chords (task 1 in Experiment 4) and ratings of whole chord sequences for C/D and P/U (task 2 in Experiment 4) show that diminished chords on the subdominant were consistently judged more consonant and pleasant than the same chord appearing in any other function. These results for diminished chords could be ascribed to familiarity: diminished triads often appear as a supertonic chord in a minor key, and a diminished chord on the subdominant is identical to a diminished seventh chord built on the supertonic (II) of the key without the root (Parncutt, 2006). In this context, diminished triads will often be followed by V and I chords to make a common harmonic progression, which is the same progression employed in this experiment: IV-V-I. This influence of familiarity seems to be consistent with the results of previous (Koelsch et al., 2000; Leino et al., 2007; Loui et al., 2005; Maess et al., 2001), in which the Neapolitan chord appearing on an unexpected function (the tonic) triggers larger negativities than the same chord on an expected function (the subdominant).

As for C/D judgements of augmented chords (task 1 in Experiment 4), no significant differences were found in the C/D judgements between functions. This may be due to the fact that the dissonant characteristics of the augmented chords were too strong to be influenced by their function, a postulation that is consistent with Johnson-Laird et al.'s (2012) finding that non-tonal chords with a strong acoustic character are less likely to be influenced by context. However, augmented triads on different functions did receive different ratings, with sequences containing augmented triads on the tonic in a major key (task 2 in Experiment 4) receiving the lowest C/D and P/U ratings. This may be due to there being a greater violation of expectation for augmented triads on the tonic, an idea that supports the second model based on the stability of chords. Diminished chords on the tonic were likewise judged to be less consonant, though this was also not statistically significant. Perhaps augmented and diminished chords on the tonic represented a larger violation because the last chord of the sequence was expected to be consonant, in order to provide a proper end to the cadence. This larger violation of expectation may also be due in part to the fact that the tonic is the most stable function (Bharucha & Krumhansl, 1983; Krumhansl, 1990), that there is a greater expectation that a cadence will end on the tonic than in any other way (Tillman & Lebrun-Guillaud, 2006), and that the sense of key and harmonic context has to be established well towards the end of a chord sequence (Koelsch et al., 2000). A greater violation of stability occurred in the case of augmented triads on the tonic because, for a variety of reasons, the expectation for a stable tonic to complete the cadence is greater than it is with the other two functions.

By contrast, the results for augmented triads do not lend support to the familiarity model. This may be owing to the fact that augmented triads on the tonic are familiar only in very particular circumstances, and that these were not to be found in the experimental stimuli. The tonic in the stimuli sequences of this experiment was in all cases the last chord of the sequence. However, augmented chords typically only appear on the tonic at some point within a sequence in order to lend the phrase a chromatic sound, and this of course represents a very different usage for the augmented chord.

The result that diminished chords on the subdominant were consistently perceived as more consonant than the same chords on the other two functions lend partial support to the third model, which is concerned with the position of the fifth note in the scale. This model predicts that the target chord will sound most consonant on the subdominant, followed by the tonic, and most dissonant when on the dominant. Although there is no statistically significant difference between the overall ratings for C/D and P/U for a diminished chord on the tonic and the same chord on the dominant, the chord was judged slightly less consonant and less pleasant on the dominant when the fifth note was the supertonic than it was on the tonic when the fifth note was the dominant, a finding that is consistent with the position of the fifth model. However, the results for augmented chords, which showed that these were most dissonant when on the tonic, do not conform to this model's predictions. It is difficult to know whether to conclude that there is some difference between the perception of the consonance of augmented and diminished triads that renders this model only partially valid, or whether the results for augmented chords in fact indicate that the model is wholly invalid.

In short, Experiment 4 confirmed that C/D is fluid, and that the C/D levels of chords vary according to harmonic function. The results for diminished triads are consistent with all three hypotheses, while the results for augmented triads are consistent only with the second model based on the stability of the function of a chord. The difference between the results obtained for augmented triads and those obtained for diminished triads may be due to the fact that the diminished triad and the augmented triad are very different types of chord: each has its own unique acoustic properties, and each has a particular role to play in musical harmony.

Fluidity 2: Presence and absence of a musical context

The comparison between chords in isolation (Experiment 3) and chords in a musical context (task 1 in Experiment 4) reveals the influence of context on C/D perception for both diminished and augmented chords. Augmented triads on the tonic and subdominant were more consonant when occurring in a context than when in isolation. The influence of context on the C/D levels of diminished triads varied: diminished chords on the dominant were more dissonant in a context than in isolation, but when they appeared on the tonic and subdominant they were more consonant in a context. As for control chords, with the exception of minor chords on the subdominant, no difference in C/D judgements was evinced between major and minor triads heard in isolation and in a musical context.

Both augmented and diminished triads were judged more consonant when they appeared on the tonic or the subdominant than when in isolation. However, C/D judgements for augmented and diminished chords differ from one another when it comes to the dominant: there is no significant difference between the C/D levels of augmented chords on the dominant and the same chords in isolation, whereas diminished chords on the dominant in both major and minor modes were judged more dissonant in a musical context than in isolation. This partly confirms the hypothesis that chords sound more dissonant when heard in an unexpected context than when heard in isolation, since, according to the second hypothesis of Fluidity 1 (the 'tonal stability of a chord's function' model), a diminished chord is not expected to sound most consonant when heard on the dominant. However, the second hypothesis of Fluidity 1 also predicts that the tonic will be an unexpected context for both augmented and diminished triads. As such, the fact that both triads were judged to be more consonant when on the tonic than when in isolation does not match the second hypothesis of Fluidity 1, and fails to support the hypothesis that an unexpected context makes chords more dissonant.

This exception of the dominant also may be due to the violation of the role of the dominant. Diminished triads often appear on the dominant in major modes as leading note chords, and are so called because they lead to the tonic to end the cadence. The dominant is, therefore, a familiar harmonic function for the diminished triad. While the diminished triads used in Experiment 4 were built on the fifth note of the scale, a leading note chord occurs on the seventh note of the scale. In order to have worked 'properly', the dominant should have led smoothly to the final tonic; but in fact the diminished triads on the fifth note of the scale in the stimuli sequences did not function in this way. These unexpected diminished triads violated the sense of a proper flow from the dominant to the tonic, and hence also violated listeners' expectations – at least, this seems like a reasonable explanation for the perceived dissonance of diminished triads on the dominant. The findings for diminished triads perhaps indicate that harmonic functions only work properly when they are comprised of the right notes of the scale, and they also suggest that participants' C/D judgements are determined more by their familiarity with authentic harmonic progressions than by the mere harmonic function of a particular chord.

The differences between chord types suggest that, as predicted, the influence of context varies according to the chord: in other words, the degree of the fluidity of C/D judgements depends on the type of chord in question. A study by Johnson-Laird, Kang, and Leong (2012) found similar results that the degree to which context influences the listener's judgements of dissonance will vary according to the particular chord being judged. This study compared tonal chords (such as major triads, minor triads, the seventh and the minor seventh) and non-tonal chords (for example, chords that do not consist of the third or fifth), and found that the former were more influenced by context than the latter. However, this result could be attributable to the characteristics of the non-tonal chords: in other words, the acoustic features of these non-tonal chords may have been too original or too different from those of orthodox tonal chords for them to be influenced by context. The qualities and characteristics of chords may contribute to the degree to which context influences the listener. In the case of this present study, the more dissonant or ambiguous the chord was in isolation, the more fluid the C/D judgements of the chord were in musical context. The results of Experiment 3 and the comparison between Experiments 1 and 2 bear this out: augmented triads were judged to be very dissonant in isolation, while diminished triads were judged to be neither particularly consonant nor particularly dissonant - that is to say, diminished triads were ambiguous. In the case of both augmented and diminished triads, their C/D levels fluctuated greatly according to context, especially diminished triads due to their ambiguity. By contrast, major triads were judged to be solidly consonant, whatever their context. Major triads have the clearest root among these four chords, according to Parncutt (1988), and their unambiguousness and stability may have enabled them to maintain their consonant identity regardless of function and context. Support for this assertion comes from Janata (1995), who found that it is more difficult and takes more time to process chords with ambiguous C/D or tonal context than it does to process those that are unambiguous, such as clearly consonant or very dissonant chords.

C/D and P/U

With regard to perceptions of P/U, the results reveal a strong correlation between these and C/D perceptions; consonant chords are generally judged to be pleasant, while dissonant chords are typically considered unpleasant. This finding agrees with the notion that C/D and P/U are commonly conflated in people's minds. However, a few listeners judged neither that consonant chords were pleasant, nor that dissonant chords were unpleasant. Guthrie and Morrill's (1928) reported incongruency between the perception of C/D and of P/U: they found that musicians judged C/D (measured in terms of fusion and smoothness) and pleasantness differently. The lack of consistency between different studies of C/D and P/U demonstrates that, despite the common assumption to the contrary, P/U and C/D judgements do not always closely match one another. This opens up the possibility for thinking that dissonance can in some instances induce pleasantness in the listener. There are moments in certain pieces of music where dissonant chords in fact sound pleasant, for instance in contexts in which the dissonant chord is resolved in an expected fashion. The pleasantness of certain dissonant chords might be attributable to the fact that, as Meyer (1956) wrote with reference to Zarlino's view on the matter, dissonance in a piece of music has an aesthetic power that 'adds beauty and elegance to the work and makes the consonance which follows more acceptable and sweet' (1956, p. 229). Perhaps more ecologically valid and rich material would be needed to better explore 'the pleasantness of dissonance'.

One criticism that might be levelled at this experiment is that the experimental method employed ignores some aspects of tonal music, namely, certain orthodox contexts and resolutions. In Experiment 4, both augmented and diminished triads were made to function in atypical contexts. Some 'typical' contexts in which they would normally appear in tonal music were overlooked due to an experimental design that prioritised the influence of function, and it cannot be denied that this increased the likelihood of making these chords more dissonant and unpleasant. This is especially the case for diminished triads on the subdominant, which were judged to be more dissonant in musical context than in isolation. According to expectation theory (Huron, 2006), an unexpected stimulus is liable to induce a negative reaction. It is by no means necessary that a dissonant chord will be an unexpected stimulus, and so expectation theory should not lead us to believe that dissonance will customarily produce a 'negative' expectancy reaction: however, unexpected occurrences of augmented and diminished triads in atypical contexts may indeed have led many listeners to respond to the experimental stimuli with surprise, confusion or annoyance. In addition to the problem of augmented and diminished chords appearing in atypical contexts, the experimental design also failed to take into account the fact that these chords are typically supposed to be resolved. It seems plausible that C/D judgements will be influenced by the way in which a chord is resolved in the real listening experience, and so this relation might be a profitable avenue for future research. Recent research shows that expected closures to chord sequences (such as dominant-tonic (V-I)) are judged to have a higher sense of completeness and belongingness within the sequence, less tension, and are more accurately and rapidly judged for consonance (in tune) and dissonance (out of tune) than unexpected closures (Bigand et al., 2003; Bigand et al., 1999; Bigand & Pineau, 1997; Steinbeis, Koelsch & Sloboda, 2006; Tillmann et al., 2008; Tillmann & Lebrun-Guillaud, 2006). In the light of these findings, one can assume that an augmented or diminished chord that is resolved in an expected way will sound more consonant than one with an unexpected resolution. Further studies should help to shed more light both on the importance of orthodox contexts for the perception of augmented and diminished chords, and on the importance of their resolution.

The present study is valuable as it provides empirical data about the influence of musical context on the perceived C/D of major, minor, augmented and diminished triads. The results confirm that the C/D and P/U of chords are influenced by musical context and harmonic function, particularly in the case of diminished triads. The degree to which a chord is influenced by these factors varies according to the type of chord in question, and stands as confirmation of the dual and contradictory character of C/D: its rigidity and fluidity.

Chapter 5

Horizontal Motion and Harmony

5.1. Study 1: Horizontal motion

Following our investigations into the influence of harmonic function in Chapter 4, the present chapter will examine another aspect of the C/D of chords in a musical context: namely, the influence of the horizontal motion of chord sequences on C/D perception. According to Tenney (1988), consonance and dissonance (C/D), as these terms are used in their modern sense, are 'phenomena of motion'. In Western tonal music, there is an urge to move from dissonance to consonance, from instability to stability, or from tension to relaxation, and this movement contributes to the music's flow and dynamism. Dissonant chords induce expectations to be resolved by the following consonant and more stable chord (Bharucha, 1984: Parncutt & Hair, 2011). The consonance level of the chord after resolution, however, may not always be the same, but may instead vary according to how the dissonant chord is resolved. In other words, the way in which the dissonant chord is anchored by the following consonant chord may determine how consonant the overall sequence will sound. Bharucha (1984) provides support for this idea: he claims that, in terms of the listener's cognitive process, a succeeding chord is more important than the chord that precedes it, On a related point, it has also been reported that the horizontal motion between tones influences the consonance of chords (Bigand, Parncutt & Lerdahl, 1996). The experiment presented here investigates how this anchoring effect influences our perception of the consonance of chords by employing chord sequences of I–V–I, and varying the horizontal motions that are used as stimuli.

5.2. Hypotheses

I: Pitch proximity and the anchoring effect

There are two contending hypotheses regarding the influence that anchoring has on the perception of chord sequences: pitch proximity, and tonal hierarchy. The first of these hypotheses postulates that one of the most important factors in shaping our perception and expectation of melodic lines is the closeness in pitch (pitch proximity) between the anchored, non-chord tone (that makes a chord dissonant) and the anchoring tone. *Pitch proximity*, which is one of the principles of the melodic expectation theory known as the 'melodic implication and realisation model' (Narmour, 1992), or the I-R model (Schellenberg, 1996, 1997: Krumhansl, 1995), derives its name from the idea that the combination of two stimuli can imply the event that follows them (realisation). On the basis of this, when there are three successive tones, the interval between the first and the second tones is called *implicative*, while the interval between the second and the third tones is called *realised*. Pitch proximity refers to the fact that listeners expect the following tone to be proximate in pitch to the preceding tone. Besides pitch proximity, Narmour (1992) outlines a further four principles that are based on Gestalt laws, and these principles are *registral direction*, *intervallic difference*, *registral return*, and *closure* (also in Schellenberg, 1996: Krumhansl, 1995). Schellenberg (1997) examined these five principles as predictive factors in determining listeners' expectations of melodic lines by quantifying each principle for 263 different short tone sequences and measuring what contribution the quantified values made to listeners' perceptions. Schellenberg concluded that the five principles can be reduced to two, namely *pitch proximity* and *pitch reversal*, as these provide the necessary combination of registral direction and registral return.

That we as listeners tend to develop expectations based on pitch proximity has been demonstrated through the use of various experimental methods. In studies by Carlsen, (1981), and by Unyk and Carlsen(1987), after being played a melody that stopped just before it was finished, listeners were asked to sing whichever following tone they felt would be the most suitable. Most listeners sang tones that were proximate in pitch to the previous tone of the melody A more commonly used and perhaps more systematic method of testing expectations based on pitch proximity is the probe tone technique, in which listeners rate on a 7-point scale how well each probe tone (for example, 7 diatonic tones or all 12 tones in a scale) fits with the last tone (Anta, 2013; Schellenberg, 1996, 1997; Schumuckler, 1989). Both methods have shown that pitch proximity is a very influential factor in shaping listeners' melodic expectations, with listeners consistently choosing tones close in pitch to the last tone of the melody.

The anchoring effect, or 'melodic anchoring' as it is sometimes termed (Bharucha,1984; 1996), is a similar theory to pitch proximity, although it focuses more specifically on the anchoring of non-diatonic tones. The way in which a non-diatonic tone is anchored by a succeeding event plays a very important role in the listener's perception. According to Bharucha (1984), since the non-diatonic tone has the effect of interfering with the listener's musical schema, this unstable non-diatonic tone must therefore be anchored by a more stable diatonic tone in order for it to be assimilated with the schema (harmonic anchoring). The anchoring tone should also be proximate in pitch to the anchored tone so that the listener can easily relate them, and thus hear the tones as a sequence (melodic anchoring). Six experiments in Bharucha's (1984) study demonstrate the validity of this principle.

Figure 5.1 shows some of the chord sequences used in the experiment. The sequences consist of three chords: I-V^+-I for experimental stimuli and I-V-I for controls in the keys of C major and F-sharp major with varying voice lines. There are three possibilities for the first

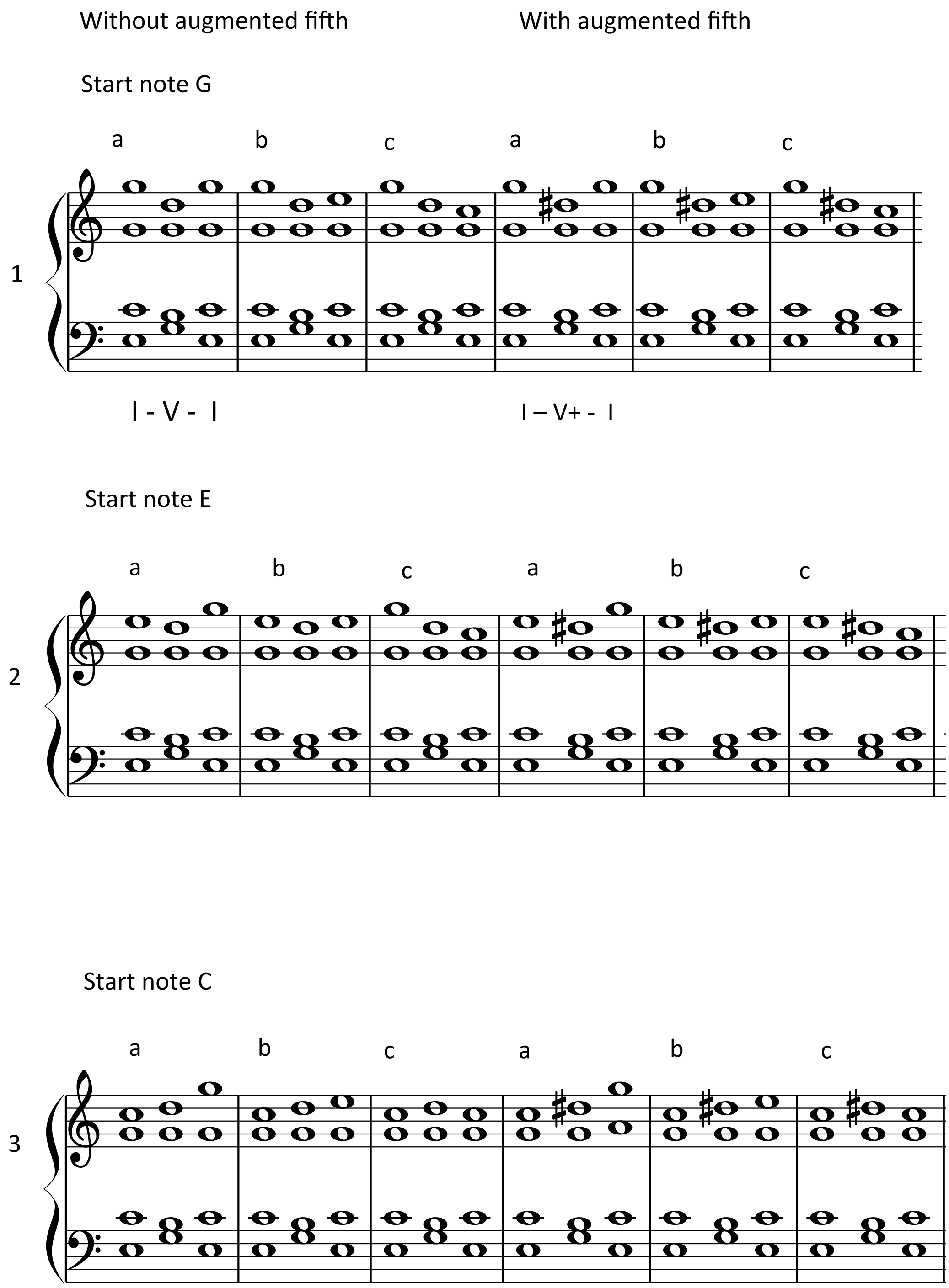

Figure 5.1. Examples of chord sequences used in Experiment 5.

Each chord sequence consists of three chords: I-V-I (the three bars on the left of each row) or I-V$^+$-I (the three bars on the right of each row). The first row, 1, shows stimuli whose top note of the first chord is the fifth; the stimuli in the second row all start with the third in their upper part; and the third row shows the stimuli with the root as their first top note. Sequences labelled *a* move upward from the top note of the middle to the top note of the last chord; *b* sequences move stepwise; and *c* sequences move downward.

and third tones of the soprano line: in the case of sequences in the key of C major, for example, the first and third tones will be either c, e, or g. The second tone of the soprano voice line is always d# so as to make the augmented chord, or just d in the case of the control stimuli. Three implicative and three realised intervals each yield a total of nine chord sequences for each key. According to the principle of pitch proximity, listeners will most expect to hear tones that are close in pitch to the preceding tone. So, for the sequences shown here, those whose non-chord augmented tone (d#) is anchored by the most proximate possible tone (e)-i.e., 1b, 2b, and 3b in Figure 5.1.-will be the most expected, and therefore may also be the most consonant. In terms of the relationship between implicative and realised intervals, a study of Mozart's piano sonatas by Bharucha (1996) found that the realised intervals in those pieces were generally smaller than the implicative intervals when the middle tone was a non-chord tone. So, if this is the case, chord sequences 3b and 1b might be more expected than 2b.

Besides pitch proximity, Schellenberg's two-factor theory of melodic expectation considers *pitch reversal* as an important factor (Schellenberg, 1997). Pitch reversal refers to the fact that listeners expect a melody to change direction after large implicative intervals of more than 7 semitones (that is, more than a perfect fifth). For example, after the downward implicative interval of A4 to C4, the following tone (which is the realised interval) is expected to move upward in pitch, perhaps, for example, to E4. Pitch reversal also considers the importance of *symmetry* in pitch: that is, listeners expect the second tone of a realised interval to be proximate in pitch (+-2 semitones) to the first tone of its corresponding implicative interval (Schellenberg, Adachi, Purdy, & McKinnon, 2002). Applying symmetry theory to the chord sequences used in this experiment, 1a, 2b, and 3c in Figure 5.1 might all be more expected and more consonant sounding than other chord sequences. Strictly speaking, the direction change principle of pitch reversal does not apply to the sequences employed in this study because the limited selection of possible first tones out of which to generate implicative intervals did not allow for large enough intervals.

II: The stability of the anchoring tone

The second hypothesis concerns the stability of the anchoring tone. The hypothesis postulates that the stability of the anchoring tone, which is determined by its position in the tonal hierarchy, will have an influence on the C/D level of chords and chord sequences. Chords and tones are considered more stable and important in the tonal hierarchy the more frequently they appear and the more important the metric beat that they occupy (Bigand, 1997; Krumhansl, 1990). Tonic chords and tones are the most frequently occurring chords and tones, and they are therefore perceived as the most important and stable, followed by dominant and then subdominant chords and tones.

Psychological approaches have revealed that stability influences various aspects of perception. For instance, there is the common expectation that, when listening to a melodic sequence, one of the more stable tones in a given key will end that sequence (Schmuckler, 1989: Anta, 2013). The stability of chords has a great influence on the perception of closure. A melody ending on the most stable tone, i.e. the tonic tone, induces a greater sense of completion than melodies ending on a less stable tone such as the dominant or subdominant (Boltz, 1989), and the same is true of chords (Tillmann & Lebrun-Guillaud, 2006). Also, listeners' judgements of whether a tone is in tune or out of tune, consonant or dissonant, are more accurate and quicker when that tone is more stable (Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003; Bigand, Tillmann, Poulin-Charronnat, & Manderlier, 2005; Tillmann, & Marmel, 2013). We can infer from these studies that the sequences in the present study may sound more consonant when the non-chord tone is anchored and resolved by a more stable tone. In the case of the sequences in this study that are in the key of C major , the sequences whose soprano line end on the tonic tone of c (i.e. 1c, 2c, and 3c) will likely be judged the most consonant and positive, followed by sequences ending on the dominant tone of g, (i.e. 1a, 2a, and 3a) and then those ending on the mediant tone of e, (i.e. 1b, 2b, and 3b).

5.3. Experiment 5: The influence of anchoring

5.3.1. Method

Participants

33 adults (Males: 13, Females: 20. Age range: 19 to 69 years, with a mean age of 28.33 years) participated in the experiment. Participants were divided into three groups according to their musical background. Eight had completed a music degree (Musicians), seventeen had had a moderate amount of music training of between three to ten years (Learners), and the remaining eight had had no formal musical lessons or training (Non-musicians).

Materials

Sequences with three chords were employed as musical stimuli (See Figure 5.1). Participants were played chord sequences consisting of I–V^+–I or I–V–I (control sequences) in either the key of C major or the key of F-sharp major with the Piano timbre. There were nine variants of the top voice line according to note; the first and third chords had either the tonic (which was C in the key of C major, and F# in the key of F# major), the median (E in the key of C major or A# in the key of F# major), or the dominant tone (G in the key of C major or C# in the key of F# major), while the middle chords always had either the supertonic (D or G#) or the augmented supertonic (D# or G##) on the top. These variations of top notes and the existence or absence of the augmented supertonic yielded eighteen patterns, so 36 sequences (18 patterns times two keys) in total. The sequences were created by Cubase software, using piano timbre, YAMAHA S90ES Piano. The duration of each chord was 0.50 seconds, and there was a 0.25-second silence between each chord, making a total length of 2 seconds for each sequence.

Procedure

There were four sessions, and each session focused on one of four variables: consonance/dissonance, pleasantness/unpleasantness, stability/instability, and relaxation/tension. In each session, all 36 sequences were presented in a random order, and participants were asked to rate the variable in question on a 7-point scale (e.g. 1 – very dissonant to 7 very consonant). The four sessions were themselves presented in a random order by an experiment running software, PsyScope. Stimuli were presented binaurally through a set of speakers or headphones according to the participant's preference, and at a comfortable volume. Participants were allowed to adjust the volume as desired before the start of experiment.

Design

The combination of a top note on the first chord ("Start Note", three levels: the tonic, the median, and the dominant), the direction of the top note of third chords ("Resolution", three levels: down, step, and up), and the existence or absence of the augmented chords in the middle of sequences ("Augmented", two levels: the supertonic or the augmented supertonic) together yield 18 conditions for each root pitch, creating 36 sequences in total.

5.3.2. Results

ANOVA (Start Note 3* Resolution 3*Augmented 2)

A three-way ANOVA with repeated measures (Start Note 3, Resolution 3, and Augmented 2) as a between-subjects factor was performed on the ratings for C/D, Pleasantness, Stability, and Relaxation. A significant effect of Start Note on Pleasantness ratings was found: F (2, 60) = 5.879, p=.005, r = .164, as the sequences that began with the mediant tone were judged more pleasant than the others. No significant differences were found between the ratings of the three groups of participants.

An effect of Resolution was found on C/D: F (2, 60) = 5.498, p=.006, r = .155, and on Pleasantness: F (2, 60) = 5.897, p=.005, r = .164. Sequences ending on the dominant tone, which were all upward sequences, were judged to be less consonant than sequences ending on the tonic (p =.032) and on the mediant (p = .022). As for pleasantness, sequences ending on the median tone were judged to be more pleasant than those ending on the dominant (p = .019). Again, no significant differences were found between the three groups for the effect of Resolution.

An effect for Augmented was found across all four variables, as sequences with an augmented chord produced more negative responses, C/D: F (1, 30) = 70.413, p = .000, r = .701, Pleasantness : F (1, 30) = 44.655, p=.000, r = .598, Stability: F (1, 30) = 78.38, p = .000, r = .723, and Relaxation : F (1, 30) = 66.63, p =.000, r = .690.

Interaction between Resolution and Augmented

There were significant interactions between Resolution and Augmented for C/D: F (2,60) = 7.138, p = .002, r = .192, and for Pleasantness: F (2,60) = 4.727, p = .012, r = .136, and Stability: F (2,60) = 4.103, p = .021, r = .120, but not for Relaxation (p > .05). Here again, the effect of Augmented and the interaction between Resolution and Augmented did not vary according to the musical experience of participants.

A one-way ANOVA was carried out with the Start Note averaged in order to further assess the effect of Augmented on each level of Resolution. The effect of Augmented was significant on all levels of Resolution on ratings for C/D, Pleasantness, and Stability ($p < .001$): sequences with Augmented were rated significantly more dissonant, unpleasant, and unstable than those without Augmented.

Another one-way ANOVA was computed separately for sequences with and without the augmented fifth, with the Start Note averaged in order to see the effect of Resolution on ratings for C/D, Pleasantness, and Stability. No significant effect of Resolution was found in the C/D ratings of sequences containing Augmented ($p = .060$). On the contrary, a significant effect of Resolution was found in the C/D ratings of sequences without Augmented ($p = < .001$), and there was a tendency for those ending on the fifth, which were upward sequences, to be rated more dissonant than both downward ($p = .001$) and stepwise sequences ($p = .015$). As for Pleasantness ratings, significant effects of Resolution were found for sequences both with and without Augmented ($p = .003$, and $p = .032$, respectively). These Pleasantness ratings showed a similar trend to C/D ratings in that upward sequences tended to be less pleasant than both stepwise sequences with Augmented ($p = .034$) and downward sequences without Augmented (p = .030). Also, stepwise Augmented sequences were judged more pleasant than upward Augmented sequences ($p = .004$). However, for Stability ratings, no significant effect of Resolution was found for sequences with or without Augmented ($p = .165$, and $p = .156$, respectively).

These analyses reveal that the effect of Augmented varies according to the effect of Resolution, and vice versa. The nature of this variation depends on how the augmented fifth

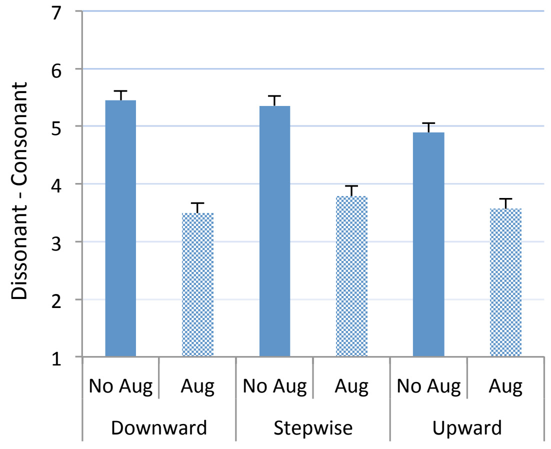

Figure 5.2. Mean ratings for C/D of Resolution and Augmented

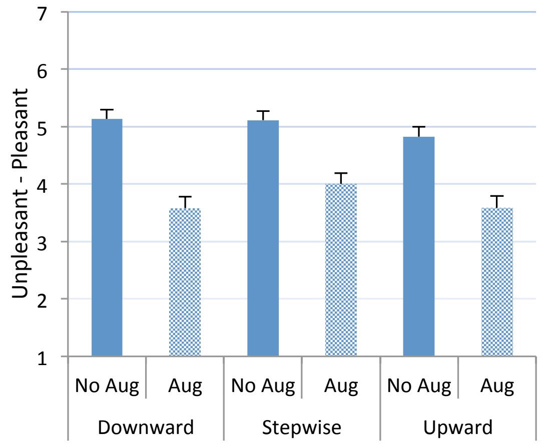

Figure 5.3. Mean ratings for Pleasantness of Resolution and Augmented

is anchored, and how stable the anchoring tone is. The fact that the augmented fifth was anchored by a diatonic tone a semitone higher, making for the smallest possible realised interval, meant that the perceived level of C/D, pleasantness, stability, and relaxation did not decrease as much as it did for larger realised intervals. In addition to the size of the realised interval, the stability of the anchoring tone seems to be an influential factor in the perception of sequences containing an augmented fifth. It seems that the more stable the anchoring tone is, the larger the violation of expectation for anchoring will be.

The effect of the number of semitones between the realised intervals

In order to see what effect the distance in semitones between a realised interval has on listener ratings, a record was made of the number of semitones between each realised interval for all listener ratings. The number of semitones varied from one to five, and the results were assessed in a one-way ANOVA to measure the effect of semitone number. A summary of the results is given in Table 5.1. No linear relationship was found between ratings for C/D and

Table 5.1.

Summary of ANOVA with polynomial contrast

	Mean	SE	df	F	*p*	H2p
C/D	4.182	.116	1	.814	.374	.025
Pleasantness	4.135	.137	1	.256	.617	.008
Stability	3.967	.109	1	11.452	.002	.264
Relaxation	4.147	.104	1	6.947	.013	.178

Pleasantness and the number of semitones ($p > .05$), whereas a linear relationship was found between the number of semitones and ratings for Stability and Relaxation.

Correlation between the four variables

Table 5.2. gives the results of the Pearson's product-moment coefficient that assessed the correlation between each group's ratings for all four variables. The general trends are very similar to what they were for the single chord experiment of Chapter 3. Ratings for all four variables are significantly positively correlated. Generally, sequences that were judged as being consonant were also considered pleasant, stable and relaxed. However, a crucial exception to the general high correlation between the four variables was that musicians did not tend to perceive consonant sequences as being also pleasant, stable, and relaxed, although their ratings for Pleasantness, Stability, and Relaxation were positively correlated.

Table 5.2.

Correlation between the ratings for Consonance, Pleasantness, Stability, and Relaxation

		Consonance			Pleasantness			Stability		
		Musicians	Learners	Non-musicians	Musicians	Learners	Non-musicians	Musicians	Learners	Non-musicians
Pleasantness	*r*	-.335	.932**	.928**						
	p	.174	<. 001	<. 001						
Stability	*r*	-.205	.945**	.954**	.891**	.975**	.937**			
	p	.413	<. 001	<. 001	<. 001	<. 001	<. 001			
Relaxation	*r*	-.246	.924**	.972**	.905**	.941**	.942**	.941**	.953**	.960**
	p	.325	<. 001	<. 001	<. 001	<. 001	<. 001	<. 001	<. 001	<. 001

5.3.3. Discussion

These results reveal that the most pleasant sounding sequences were ones for which the soprano line begins and ends on the mediant, such as a soprano line of e–d–e when in the key of C major. In other words, the most pleasant sequences were those whose notes of the soprano line move to notes that are close in pitch, and that therefore form small implicative and realised intervals. The starting note was found to have an effect on judgements of Pleasantness only. On the other hand, the effect of Resolution was significant, which means the last note was important in determining judgements of both C/D and Pleasantness, as Bharucha's anchoring theory (1984) suggests. The sequences that ended on the dominant, which contained relatively large upward realised intervals, were judged to be less consonant and pleasant than downward and stepwise intervals. These results are consistent with the pitch proximity principle, and provide excellent support for anchoring theory, which claims that, when an unstable, dissonant, or non-diatonic tone is heard, a diatonic tone that is proximate in pitch is most expected and most likely to follow. By contrast, the hypothesis based on the tonal stability of the final tone was not a good predictor of listener perception, which suggests that a more important factor for ensuring better sequence judgements is that the non-diatonic tone is followed and anchored by a tone close in pitch rather than by one with more stability.

A significant effect of Augmented was also found, in this case in all four ratings, which indicates that sequences with a V^+ chord in the middle were perceived as more dissonant, unpleasant, unstable and tense. The interaction between the effect of Augmented and Resolution revealed an interesting fact: the effect of Augmented depends on Resolution, which means that ratings for sequences with and without Augmented vary according to their final note (Resolution). For example, the perception of sequences ending on the tonic differ the most according to whether the sequence has an augmented fifth as its second chord, whereas ratings for sequences ending on the mediant (which makes the smallest realised interval) were not much influenced by the presence or absence of the augmented fifth. In other words, the difference between ratings for e-d-c and e-d#-c was notably bigger than the difference between ratings for e-d-e and e-d#-e. The results also show that ratings for sequences with three different Resolutions (e.g. c, e, g in the key of C major) were less varied for Augmented sequences than they were for non-Augmented, control sequences. This suggests that listeners' perceptions in the Augmented condition were equally negative regardless of Resolution (the final note), and that Resolution had little influence on ratings for sequences with Augmented.

In summary, Experiment 5 showed that the short chord sequences I- V^+- I were perceived as most consonant and pleasant when the augmented fifth tone of V in the soprano line (e.g. d# when the sequence was in the key of C major) was anchored by a diatonic tone closest in pitch (e.g. e). This finding is in accordance with pitch proximity principles (Narmour, 1992: Schellenberg, 1996, 1997).

However, Experiment 5 had a limitation: namely, that it did not distinguish between the direction (Resolution) of the realised interval and the notes of the last chord. This resulted from the fact that there were three possibilities for the direction of the top line from the middle to the third chord: upward, step, or downward. Upward was always the fifth note of I, while step and downward were the third and root, respectively. Therefore, it was not clear whether the effect of Resolution was due to the direction of the intervals or to the stability of last note. Also, Experiment 5 examined only three sizes of interval, when a greater variety of interval sizes might have helped to yield clearer differences. Further experiments will be conducted to study these issues.

5.4. Study 2: The influence of horizontal motion and harmony

In order to distinguish the effect of direction and of the last note, we employ seven diatonic chords as the third chord of the sequences in Experiment 6. The sequences used in Experiment 6 contain three chords, I, V or V^+, and one of seven diatonic chords with three different possibilities of top note. These top notes vary from 6 semitones below to 5 semitones above the top note of the middle chord. Unlike Experiment 5, the direction (Resolution) and the note (root, third, or fifth) of the last chord were independent, which made it possible to distinguish the influence of these two factors.

In addition to helping us to discern the effects of anchoring and pitch proximity, another aim of Experiment 6 is to examine the influence of harmony on the effect of anchoring. Experiment 6 employs seven diatonic chords for the third chord of each sequence. The question that arises here is whether the effect of anchoring varies according to the influence of harmony when the last top note is shared by a couple of possible chords. For example, a short chord sequence with a soprano line e-d#-e, in which the final e is as proximate in pitch as possible to d#, has a number of potential harmonic progressions, such as I-V-I, I-V-iii, or I-V-vi. Even though the non-diatonic tone of d# is anchored by the closest possible diatonic tone of e, the C/D level of the sequence may differ according to the harmony of the final chord that runs underneath the soprano line.

5.5. Hypotheses

I: Tonal stability and harmonic progression

Four possible hypotheses can be proposed in response to this question: the first makes reference to the stability of chords and to common patterns of harmonic progression; the second relates to the acoustic similarities between the middle and third chords; the third concerns the realised intervals between the top note of the middle and third chords; and the fourth relates to the chord type of the final chord.

On this first hypothesis, it is suggested that the way in which a short chord sequence is perceived will depend on the stability and importance of that sequence's final chord in the tonal hierarchy. The sequence will be perceived as more consonant, pleasant, stable and relaxed when it ends with a chord that is more tonally stable and important, such as I. Previous studies (Krumhansl, 1990) have shown that listeners perceive the tonic chord as the most stable, followed by the dominant and subdominant, a result that is consistent with music theory. As mentioned in discussion of Experiment 5, it has been shown that the stability of the final tone or chord of a sequence has the power to influence the listener's perception of the whole sequence (Boltz, 1989; Tillmann & Lebrun-Guillaud, 2006). According to Krumhansl (1990), listeners' ratings of the fittingness of various chords to a major key context show that the vi chord is less important and stable than the I chord, and that the iii chord is one of the weakest harmonic functions. Otsuka, Kuriki, Murata, and Hasegawa (2008) also found that listeners gave higher stability ratings to the I chord than they did to the

VI chord. Neuromagnetic imaging showed that the VI chord elicited larger N1m in the left hemisphere than was elicited by the I chord, suggesting that cortical activity at the N1m latency was involved in chord judgement (Otsuka, Kuriki, Murata, & Hasegawa, 2008). Both behavioural data and MEG data from this study revealed that harmonic function plays an important role in the perception of chords rather than merely sonority. Acoustically identical chords changed their stability according to their harmonic function, a phenomenon that has also been reported in studies employing event-related potentials (ERPs) (Koelsch, Gunter, Friederici, & Schroeger, 2000; Leino, Brattico, Tervaniemi, & Vuust, 2007; Loui, Grent-'t-Jong, Torpey, & Woldorff, 2005; Maess, Koelsch, Gunter, & Friederici, 2001).

This prediction–that the sequence ending with a more stable and important chord will be judged as more consonant than those ending with a less stable chord–can also be explained with reference to common patterns of harmonic progression that appear in Western tonal music. According to music theory, there are rules that govern the ways and the sequences in which chords are supposed to appear. For instance, when a sequence opens on the tonic chord I, the following chord will often be IV, or V, sometimes VI, or, in rarer cases, II or III (Piston, 1950). Empirical studies show that listeners have implicit knowledge of the harmonic relations between chords that differ in their tonal stability, and that the knowledge stored in our in musical schema is used to make perceptual and cognitive judgements. Krumhansl, Bharucha, and Kessler (1982) demonstrated this implicit knowledge by asking listeners to judge the relatedness of chords. Their findings show that the relationship between chords is consistent with music theory, which holds that V, and IV share a particularly close relationship with the tonic, I, while VI, II, and III were less close to it. In a study by Schmuckler (1989), when listeners were presented with unfinished excerpts from a Schumann lied followed by seven probe chords, the chords that listeners most often anticipated were also those that music theory decrees should most commonly follow. Further, common patterns of harmonic progression are capable of influencing listener judgements of the fittingness of a melody, even when the harmony is only implied by notes in that melody rather than being explicitly presented by the accompanying chords (Jansen & Povel, 2004; Povel & Jansen, 2002). These melodies were judged better when they implied more common harmonic progressions than when the tones in the melodies implied less common harmonies. These studies demonstrate that listeners' perceptions are based on and restricted by the patterns of harmonic progression that listeners file under 'common' in their musical schema.

From the above, it can be inferred that patterns of harmonic progression will be an important factor in determining listener perceptions of short chord sequences. In music theory, I is the chord that most commonly follows V, followed by VI and IV. III and II after V occur 'less often' (Piston, 1950, p. 17). Table 5.3 summarises data on: the probability of a variety of harmonic progressions in baroque music (Budge, 1943); the frequency of occurrence of each diatonic chord after V in Bach's chorales (Rohrmeier & Cross, 2008) and in a selection of Rock music from the 1950s to the 1990s (De Clercq & Temperley, 2011); and behavioural data from Krumhansl (1990) on listeners' ratings of the fittingness of each chord following a chord of V. The three statistical data sets show that I is the most commonly occurring chord after V, followed by vi and IV, while ii and iii are much more rare. V and vii^{o} have almost zero percent probability of following, and often data for these chords was not even collected. This is consistent with music theory and the rank order of listener ratings on the fittingness of a selection of following chords to V. On the basis of these findings, the prediction is that a sequence will be judged as more consonant in situations in which V is followed by a more commonly occurring chord.

II: Psychoacoustic similarity

The second hypothesis is based on the psychoacoustic similarity between the second and third chords of the sequence. The prediction is that a chord sequence will be judged more consonant, pleasant, stable and less tense the more acoustically similar two successive chords are to each other. It is considered that having tones (frequencies) in common is one of the conditions required for two chords to share a strong harmonic relationship (Bigand, Parncutt, & Lerdahl, 1996; Parncutt & Lerdahl, 1997). There are two principal ways in which the psychoacoustic similarity of two chords can be measured. The first and simplest of these is to count the number of tones that the two chords share in common. For example, the number of tones that the chords of I, iii, and vi share with the chord of V are 1, 2, and 0, respectively

Table 5.3

Harmonic progression from V to each diatonic chord.

This table summarises the frequency of occurrence, in percentage terms, of harmonic progressions from V to each chord, listeners' ratings of the fittingness of each chord in a C major key context, and pitch commonality values between V and each diatonic chord.

		I	ii	iii	IV	V	vi	vii^{o}
Percentages of harmonic progression from V to following chord	Baroque music (Budge, 1943)	79.3%	2.1%	2.1%	3.9%	NA	11.9%	0.5%
	Bach's Chorales (Rohrmeier and Cross, 2008)	8.98 (55.09%)	0.51 (3.12%)	0.55 (3.37%)	0.63 (3.86%)	NA	1.28 (7.85%)	0.01 (0%)
	Rock music (De Clercq and Temperley, 2011)	788 (52.95%)	36 (2.41%)	17 (1.14%)	392 (26.34%)	0	191 (12.83%)	0
Listeners' ratings on the fittingness of each chord to C major key context (Krumhansl, 1990)		6.66	3.12	2.76	5.59	5.33	3.62	2.64
Pitch commonality value between V and each chord (Bigand et al., 1996)		.32	.39	.46	.12	1.00	.06	NA

(e.g. When V is GBD in the key of C major, I (CEG) shares G, iii (EGB) shares G and B, vi (ECA) shares none). On the basis of Terhardt's virtual pitch theory, Parncutt (1989, 1993) and Thompson and Parncutt (1997) suggested and formulated the notion of *pitch commonality*. Pitch commonality refers to 'the degree to which the sounds evoke tone sensations whose pitches coincide across the two sounds' (Parncutt, 1989, p. 60). Pitch commonality considers that an implied pitch that is not notated and perhaps not even physically played can nonetheless influence the perceived relationship between two chords. This pitch commonality can be calculated from the salience of all the pitches evoked by the first and second chords. Pitch commonality has generally enjoyed a great deal of success in predicting listener perception. For instance, two successive chords with a higher pitch commonality were found to induce lower perceived tension (Bigand, Parncutt & Lerdahl, 1996), and were judged as having a better fit between first and second chords (Thompson & Parncutt, 1997). Notwithstanding this success, pitch commonality did not provide a reliable guide to listener judgements of structural stability in atonal music (Dibben, 1997). Psychoacoustic similarities between chords have a large influence on listener perception, but this influence operates in different ways depending on the stimuli in question. For instance, the acoustic features of sound (a bottom-up paradigm) plays a more important role than does tonal hierarchy (a top-down paradigm) in the perception of isolated chords and short chord sequences, while tonal hierarchy is a more important factor in the perception of longer sequences (Parncutt & Bregman, 2000; Tekman & Bharucha, 1998).

Table 5.3. shows the pitch commonality values for the V and for seven possible following diatonic chords taken from Table 2 of Bigand, Parncutt and Lerdahl (1996) (p.130). The values formulated as a correlation coefficient between the two chords are transposable for any pitch chroma (Parncutt, personal communication). According to this data, the rank order of pitch commonality values from highest to lowest are; V, iii, ii, I, IV, and vi (the

commonality values for V and vii° were not included in the original data). This rank order is in accordance with the number of tones shared between V and the following chords; V shares three notes with V (*g*-*b*-*d* and *g*-*b*-*d*); iii and vii° each have two shared notes (*g*-*b*-d, and e-*g*-*b*; g-*b*-*d* and *b*-*d*-f); and I and ii share one note with V (*g*-b-d, and c-e-*g*; g-b-*d*, and *d*-f-a).

III: The types of final chord

The third hypothesis is based on the type of last chord within the sequence. The prediction is that sequences ending with a major chord (I, IV, or V) will be more consonant than those that end with a minor (ii, iii, or vi) or diminished chord (vii°), on the grounds that chord type is an influential factor in determining the C/D of a chord sequence. Many empirical studies have reported that major chords are perceived as the most consonant chord type, followed by minor and diminished chords, and that augmented chords are the most dissonant (as in Experiment 5, Chapter 2; Johnson-Laird, Kang, & Leong, 2012; Roberts, 1986). This effect of chord type, it is thought, may also be applicable to the perception of chord sequences.

IV: Horizontal motion

Finally, the fourth hypothesis concerns horizontal motion: that is, the size of the realised interval between the middle and final chords. The results of Experiment 5 revealed that sequences with larger realised intervals (ascending 5 semitones) were perceived as less consonant than those with smaller realised intervals (ones that ascended or descended 2 semitones), which is in accordance with the principle of *pitch proximity*, according to which listeners expect realised intervals to be small. Pitch proximity is generally a good predictor of listener expectation of melodic intervals (Anta, 2013; Thompson, Cuddy, & Plaus, 1997; Schellenberg, 1997; Schellenberg et al., 2002). However, in contrast to pitch proximity, which posits a negative linear relationship between the pitch distance of an interval and its perception, the relationship between interval size and C/D perception is not linear. C/D perception does not correspond neatly with interval size, as can be seen from the fact that consonant intervals, such as unison, the octave, and the perfect fifth, vary greatly in size. This assertion is supported by Vos and Pasveer's study (2002) in which they found that the degree of consonance or dissonance of an interval was one of the most important factors when it came to ratings of its 'goodness'. Experiment 6 will examine the effect of the size of the realised interval as measured in semitones, and of the realised interval's C/D on perceptions of the chord sequence.

Another issue regarding realised intervals is their direction. According to the theory of *pitch reversal*, implicative and realised intervals are expected to move in opposite directions (as mentioned before). Experiment 6 will test whether this expectation of pitch reversal is borne out by employing a wider variety of realised intervals than were used in Experiment 5. Previous studies have reported mixed results when it comes to corroborating the effect of direction. Anta (2013) found that, in the case of small intervals in a melody, the direction of the interval was not an influential factor. A study by Jansen and Povel (2004) did not distinguish between melodies consisting of three ascending notes of a chord (e.g. c-e-g) from melodies with three descending notes (g-e-c). Listeners gave higher 'goodness' ratings to melodies that had three ascending or descending notes than to melodies with three notes in a mix of directions, such as e-g-c or g-c-e, which seems to conflict with the pitch reversal principle. However, in a study by Vos and Pasveer (2002), direction was found to be an important factor for non-musicians' 'goodness' ratings of intervals: ascending intervals were preferred for the beginning of the melody, while descending intervals were preferred for the closing of the melody. From this it can be hypothesised that, if there is any effect of direction, then it is likely that realised intervals with a downward direction will be heard as more consonant than those with an upward direction because the realised intervals close the sequence.

In sum, Experiment 6 will examine both the effect of anchoring on the perception of chord sequences, and the influence of harmony on the effect of anchoring. There are four hypotheses regarding the influence of harmony, which are as follows:

1. The perception of a chord sequence depends on the tonal stability and importance of its final chord. The more stable and important the final chord is in the tonal hierarchy, the more consonant, pleasant, stable and relaxed the sequence will be.
2. The perception of a chord sequence depends on the acoustic similarities between the second and final chords. The more similar the two chords are, the more consonant, pleasant, stable and relaxed the sequence will be.
3. The perception of a chord sequence depends on what type of final chord it has. A sequence will be most consonant, pleasant, stable and relaxed when the final chord of the sequence is a major chord, and a minor chord would be the next most consonant ending. A sequence will be least consonant, pleasant, stable and relaxed when the final chord is a diminished chord.
4. The perception of a chord sequence depends on the size, direction, and C/D of its realised interval. A sequence will be most consonant, pleasant, stable and relaxed when its realised interval is small in pitch, moves in a downward direction, and is consonant.

5.6. Experiment 6: the influence of horizontal motion and harmony

5.6.1. Method

Participants

42 adults (male: 23, female: 19. Age range 21 to 77 years, with a median age of 32.50 years) took part in the experiment. Participants were again divided into three groups depending on their musical background. 14 of the participants were classified as musicians, and they were those who had a music degree in performance, composition or musicology (Musicians). 17 participants had had some level of formal musical training between the ages of 10 months and 18 years, with the average length being 6.29 years (Learners). The remaining 11 participants had had no formal musical training (Non-musicians).

Material

As in Experiment 5, sequences with three chords were used as musical stimuli. The examples of stimuli are shown in Figure 5.4. The first chord was always I, while half of the sequences had V for the second chord and the other half had V+. There were seven variations for the third chord, which were I, ii, iii, IV, V, vi, and vii^{o}. The third chord was presented with different inversions, which made for three variations of final top note (the root, third or fifth). The inversion of the first chord also varied as a between-subjects factor.

The sequences were played in the key of C major or F# major, with a piano timbre (YAMAHA S90ES Piano) created by Cubase. The total length of each sequence was 2 seconds. The duration of each chord was .50 second, and there was .25 second silence between each chord.

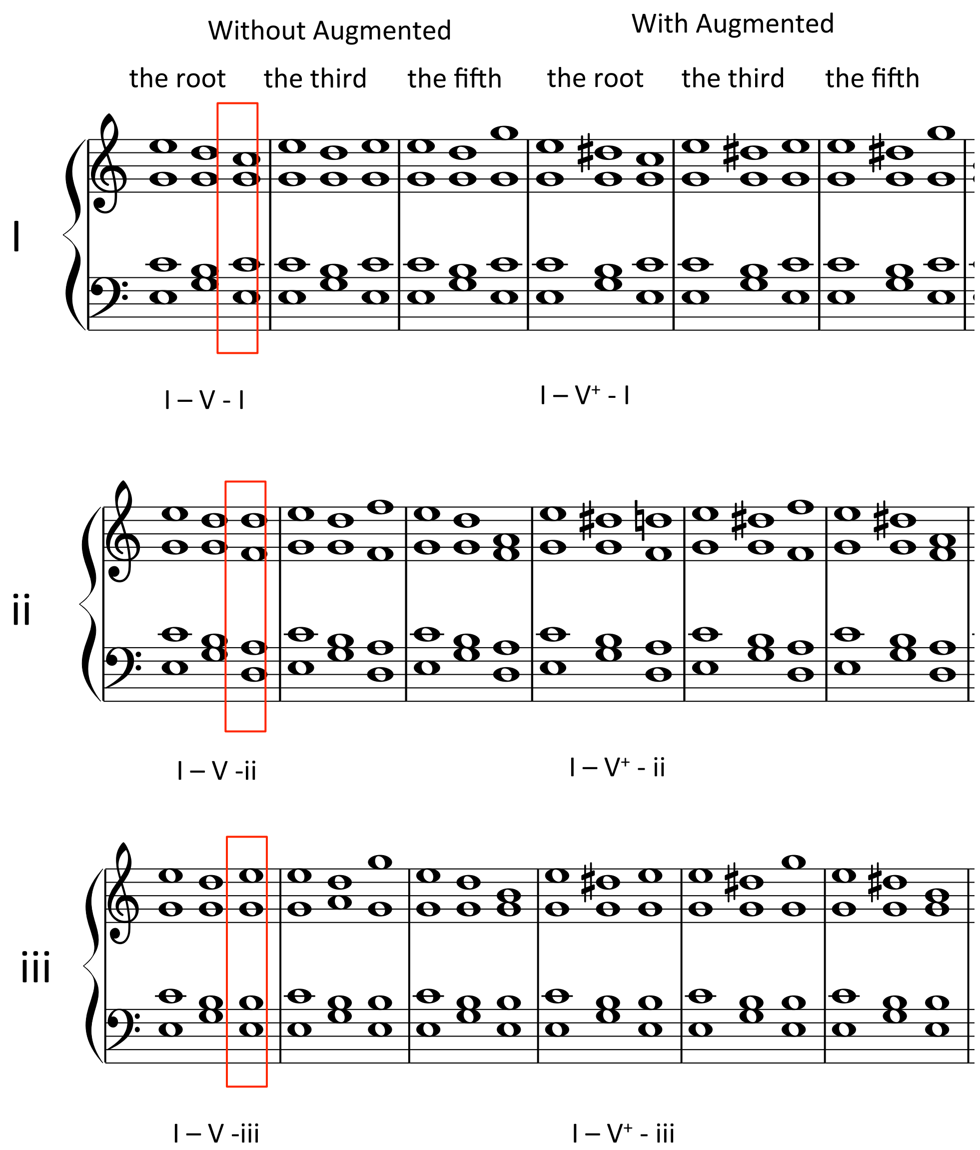

Figure 5.4. Examples of stimulus chord sequences. The chord sequences consist of three chords, whose final chords vary from I to vii°. The top notes of the first and the final chords are in all cases either the root, third, or fifth of the chord. The figure shows only sequences starting on the third.

Procedure

The procedure was largely the same as Experiment 5. One difference, however, was that there were 42 musical stimuli in one session rather than 36.

Design

The final chord ("Chord", seven levels: I, ii, iii, IV, V, vi, or vii^{o}), the top tone of the final chord ("Last Note", three levels: the root, the third, or the fifth), and the existence or absence of the augmented fifth in the second chord ("Augmented", two levels: with or without) yield 42 conditions. The data for the keys of C major and F sharp major were averaged for the analysis.

5.6.2. Results

ANOVA: Main effects

A mixed ANOVA with three within-subjects factors (Chord, Last Note, and Augmented) and two between-subjects factors (Start Note, and Musical Background) computed the ratings of the four variables. The results of significant main effects and significant interactions are summarised in Table 5.4. As for the significant main effect of Chord, all four ratings varied according to the final chord of the sequence. A pairwise comparison shows that sequences ending with I tended to be rated higher, while those ending with vii^{o} were judged most negatively, followed by ii. Ratings for sequences ending with vii^{o} were significantly lower than for sequences ending with any other chord ($p < .001$). As for the effect of Last Note, sequences whose last top note was the fifth tended to be more negatively perceived than sequences ending with the root or third, and the difference between Pleasantness ratings for sequences ending with the third and the fifth was significant ($p = .02$). A main effect of

Augmented confirmed that in all four ratings, sequences with an augmented chord were judged more negatively ($p < .001$), a result that is consistent with Experiment 5. There was no significant main effect of between-subjects factors, Musical Background or Start Note ($p > .05$).

A mixed ANOVA also revealed some interactions among factors. There were five two-way interactions (Chord and Last Note, Chord and Augmented, Chord and Musical Background, Chord and Start Note, Augmented and Musical Background), and two three-way interactions (Chord, Last Note, and Musical Background, and Last Note, Augmented, and Musical Background). The detail of each interaction will be reported.

Table 5.4.

Summary of the results of a mixed ANOVA

	Consonance			Pleasantness			Stability			Relaxation		
	F	*p*	η^2_p	*F*	*p*	η^2_p	*F*	*p*	η^2_p	*F*	*p*	η^2_p
Chord	33.83	<. 001	.50	12.84	<. 001	.28	25.48	<. 001	.43	30.58	<. 001	.48
Last Note	1.09	.342	.03	4.27	.012	.12	.50	.606	.01	2.13	.126	.06
Augmented	91.99	<. 001	.73	94.44	<. 001	.74	92.06	<. 001	.73	68.64	<. 001	.67
Chord*Last Note	3.30	<. 001	.09	2.99	.003	.08	2.33	.004	.06	1.70	.064	.049
Chord*Augmented	2.85	.011	.08	3.40	.003	.09	3.95	.001	.10	3.63	.002	.09
Chord*Start Note	1.17	.312	.06	2.09	.038	.11	1.47	.167	.08	2.30	.019	.12
Chord*Musical Background	1.39	.023	.078	2.28	.023	.078	1.43	.186	.122	2.14	.024	.080
Augmented*Musical Background	4.04	.027	.19	2.17	.130	.11	3.09	.059	.15	2.48	.099	.13
Chord*Last Note* Musical Background	1.17	.286	.06	1.35	.165	.07	.56	.903	.03	1.78	.034	.09
Last Note* Augmented*Musical Background	1.00	.410	.05	2.46	.054	.13	.98	.423	.05	3.14	.020	.16

Interaction between Chord and Last Note

As a mixed ANOVA revealed the interaction between Chord and Last Note, a one-way ANOVA was carried out separately for each Chord, with the Start Note averaged so as to further examine the effect of Last Note. The mean ratings are summarised in Figures 5.5, 5.6, 5.7, and 5.8. For sequences ending with I, these were rated more positively when their last note was the third (e.g. an e in the key of C major) than when it was the fifth (e.g. g in C major) ($p < .05$), which is consistent with the results of Experiment 5. In the case of sequences ending with ii, a significant main effect of Last Note was found on C/D: F (2, 82) = 3.20, $p = .046$, $\eta^2_p = .07$, and Pleasantness: F (2, 82) = 4.67, $p = .012$, $\eta^2_p = .102$. A pairwise comparison shows that only pleasantness ratings had a significant difference between the root and the third ($p = .029$). In the progression of V – ii, sequences were more pleasant when the top note remained on the d (the root of ii) rather than when it moved from d to f (the third of ii). There was no significant main effect of Last Note on sequences ending with iii and IV. As for V, a significant main effect was found for Pleasantness ratings: F (2, 82) = 3.31, $p = .041$, $\eta^2_p = .075$, and for Stability ratings: F (2, 82) = 5.27, $p = .007$, $\eta^2_p = .114$. Sequences with a

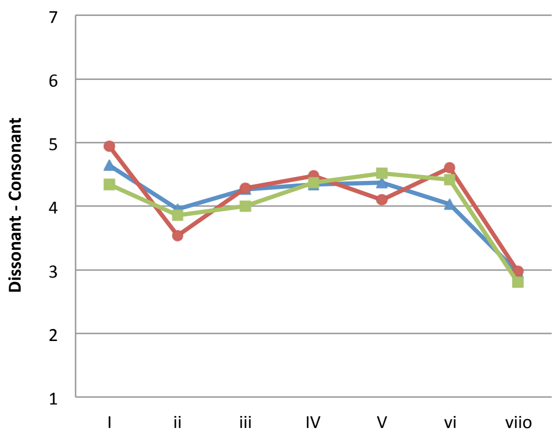

Figure 5.5. Mean ratings of C/D for Chord and Last Note

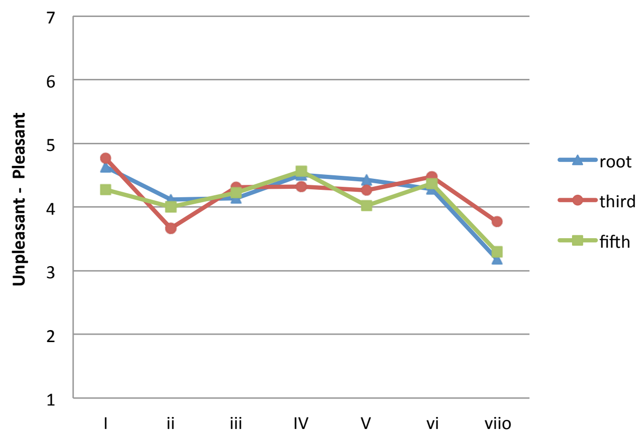

Figure 5.6. Mean ratings of Pleasantness for Chord and Last Note

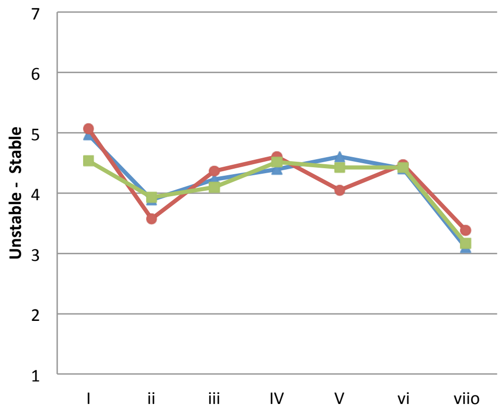

Figure 5.7. Mean ratings of Stability for Chord and Last Note

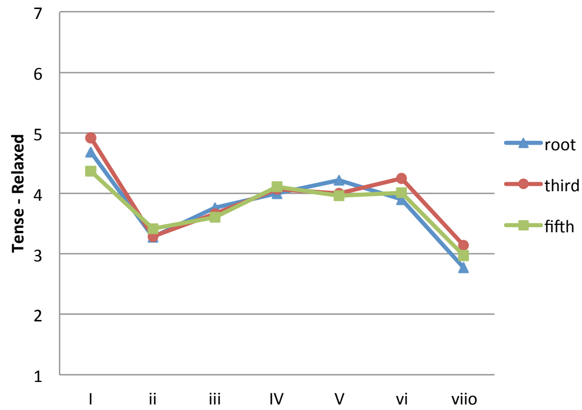

Figure 5.8. Mean ratings of Relaxation for Chord and Last Note

root of V as the last top note (e.g. a root of g in the case of a GBD chord in the key of C major) tended to be judged as more pleasant and stable, while sequences whose last note was the third of V were rated more unstable (p = .024). As for the sequences ending with vi, there was a significant main effect of Last Note on C/D ratings: F (2, 82) = 5.03, p = .009, η^2_p = .109, and a pairwise comparison revealed that sequences with the third as their last note were judged to be more consonant than when the last note was the root (p = .014). Lastly, for vii^o, there was a significant main effect of Last Note on the ratings of Pleasantness: F (2, 82) = 7.50, p = .001, η^2_p = .155, and of Relaxation: F (2, 82) = 3.48, p = .035, η^2_p= .078. Sequences ending on the third were judged more pleasant and relaxed than sequences with the root as the last note (p = .001, p = .024, respectively).

Interaction between Chord and Augmented

A mixed ANOVA also reveals a significant interaction between Chord and Augmented. A one-way ANOVA was conducted for each chord, with Last Note averaged in order to see in detail the effect of Augmented. There was a significant main effect of Augmented on all ratings of all chords (p < .001). As can be seen from Figures 5.9, 5.10, 5.11, and 5.12, a pairwise comparison shows that the existence of an augmented fifth in the middle chord of a

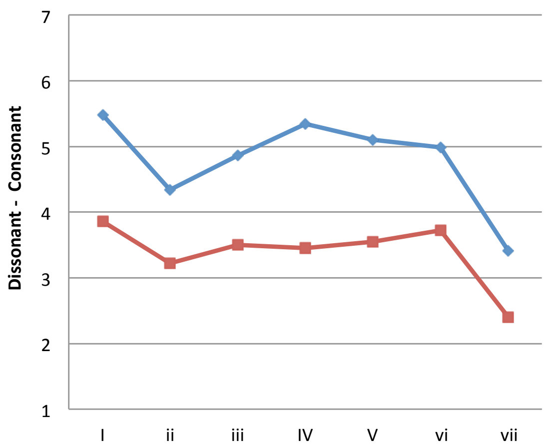

Figure 5.9. Mean ratings of C/D for Chord and Augmented

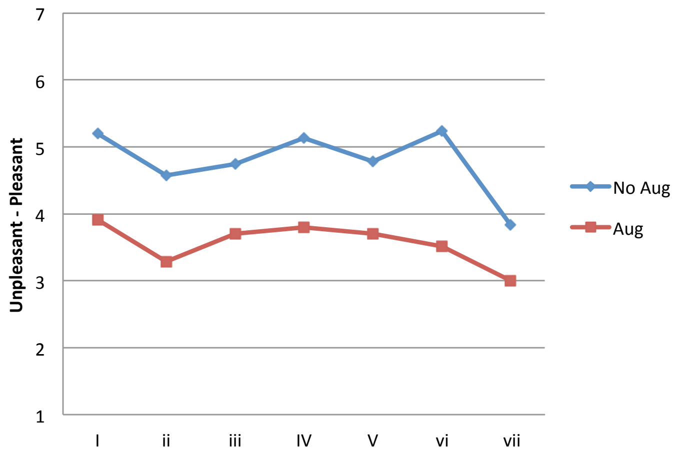

Figure 5.10. Mean ratings of Pleasantness for Chord and Augmented

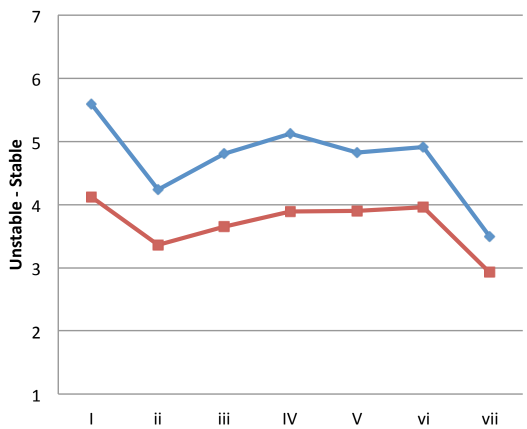

Figure 5.11. Mean ratings of Stability for Chord and Augmented

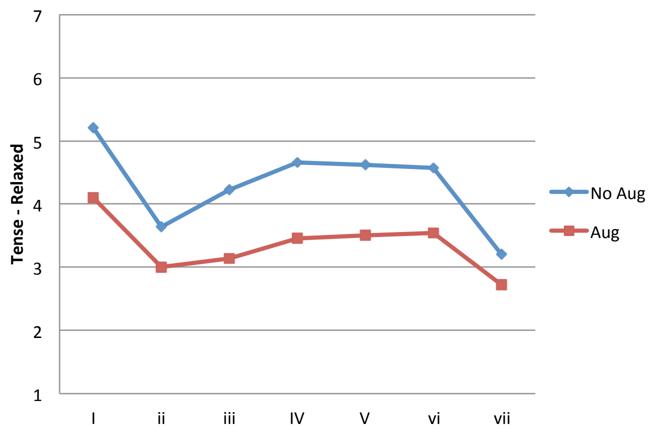

Figure 5.12. Mean ratings of Relaxation for Chord and Augmented

sequence made all four ratings significantly lower than for any sequence without an augmented fifth ($p < .001$).

Interaction between Chord and Start Note

A one-way ANOVA was likewise carried out to assess the influence of Chord on Pleasantness and Relaxation ratings for each level of Start Note, and figures 5.13 and 5.14 show the mean ratings. There was a significant main effect of Chord on almost every Start Note and on both ratings ($p < .05$), with the exception of Pleasantness ratings for sequences starting with the third (p = .084). A pairwise comparison showed that, when it came to sequences starting with the root, ratings for both Pleasantness and Relaxation were lower for sequences ending with a vii^o chord than for those ending with a I, IV, or vi (p <.05). Sequences ending with a vii^o chord also had lower Pleasantness – though not lower Relaxation - ratings than those ending with a iii (p = .014). On the other hand, for sequences starting on the third, no significant difference was found between the rating of each chord. As for sequences starting on the fifth, these were rated as more tense when ending with a vii^o than when ending with a I, iii, V, or vi (p <.05), and no significant difference was found between their Pleasantness ratings. A one-way ANOVA with Start Note as an independent variable revealed that the effect of Start Note was not significant for the ratings of any Chord. These results show that, while the effect of Chord varies according to Start Note, there is no significant difference between sequences starting with different notes for any Chord.

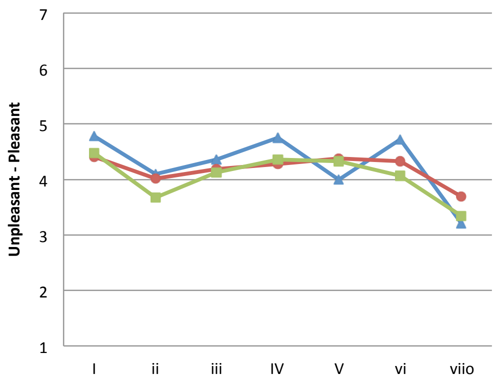

Figure 5.13. Mean ratings of Pleasantness for Chord and Start Note

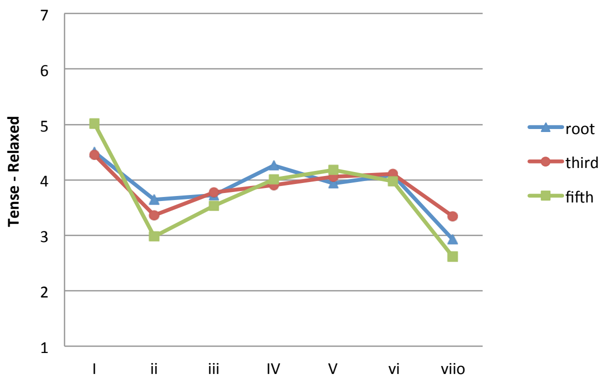

Figure 5.14. Mean ratings of Relaxation for Chord and Start Note

Interaction between Chord and Musical Background

In order to analyse in detail any interaction between Chord and Music Background for Pleasantness and Relaxation ratings, a one-way ANOVA with Chord as an independent variable was carried out for each level of Musical Background. The means of ratings for Pleasantness and Relaxation are shown, respectively, in Figures 5.15. and 5.16. A significant main effect of Chord was found for both Pleasantness and Relaxation ratings across all groups ($p < .05$). The effect of Chord was significant at a level of .001 for ratings of both musicians and learners. However, p values for the Pleasantness and Relaxation ratings of non-musicians were slightly higher (p =.039, and .047, respectively), and the effect size was η^2_p= .193 and .186 respectively, which is smaller than musicians' and learners' Pleasantness and Relaxation ratings (musicians: η^2_p = .466 and .609. learners: η^2_p = .325 and .529). As can be seen from Figure 5.15, the ratings of non-musicians were flatter than those of musicians and learners. A further one-way ANOVA with Musical Background as an independent variable was carried out for each level of Chord. The results reveal that there was no

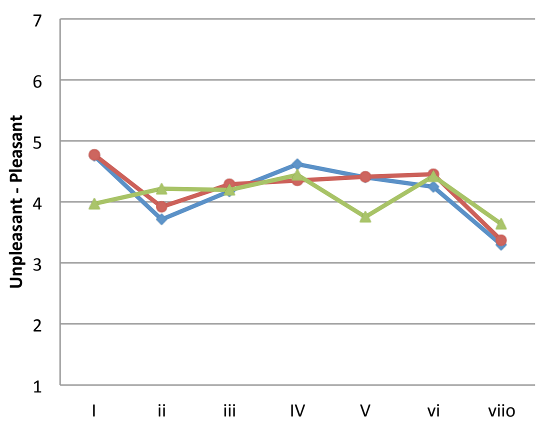

Figure 5.15. Mean ratings of Pleasantness for Chord and Musical Background

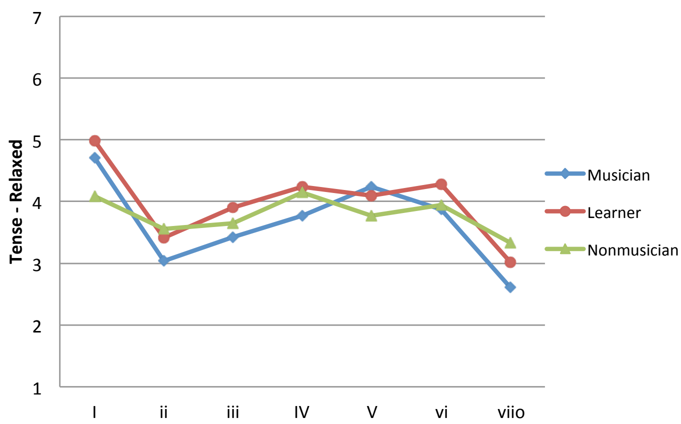

Figure 5.16. Mean ratings of Relaxation for Chord and Musical Background

significant main effect of Musical Background for any chord in either rating, with the exception of an effect on Relaxation ratings from a single sequence ending with I: F (2, 39) = 3.40, p = .044, which non-musicians rated as less relaxed than musicians and learners. These results suggest that the effect of Chord is to some extent dependent on Musical Background, and that this effect is less pronounced for non-musicians.

Interaction between Augmented and Musical Background

A one-way ANOVA with Augmented as an independent variable revealed that at all levels of Musical Background, the effect of Augmented was significant on C/D ratings; Musicians: F (1, 13) = 73.233, p < .001, η^2_p = .849, Learners: F (1, 16) = 79.573, p < .001, η^2_p = .649, and Non-Musicians: F (1, 10) = 12.376, p = .006, η^2_p = .553. As can be seen from Figure 5.17, all participant groups judged sequences containing an augmented chord as more dissonant. Another one-way ANOVA with Musical Background as an independent variable showed that there was no significant effect of Musical Background either with augmented (p = .287) or without augmented (p = .111). This indicates that the presence or absence of Augmented made a big difference to listener ratings regardless of their musical expertise.

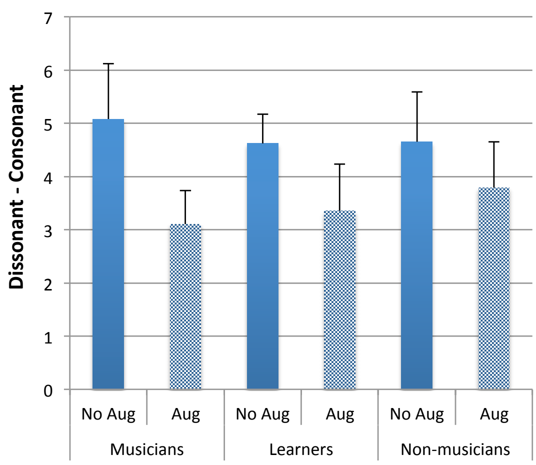

Figure 5.17. Mean ratings of C/D for Augmented and Musical Background

Interaction between Chord, Last Note, and Musical Background

Figures 5.18, 5.19, and 5.20 display the mean ratings of Relaxation per Chord and Last Note for each group. A two-way ANOVA with Chord and Last Note was conducted for each level of Musical Background. In the case of musicians' ratings, a significant main effect of Chord was found: $F\ (2.85, 37.14) = 20.22$, $p < .001$, $\eta^2_p = .609$, while no significant main effect of Last Note was found: $F\ (2, 26) = 2.86$, $p = .075$, $\eta^2_p = .181$. There was also a significant interaction between Chord and Last Note: $F\ (4.80, 62.41) = 2.73$, $p = .029$, $\eta^2_p = .174$. This suggests that the effect of Last Note varied according to Chord: as can be seen from Figure 5.18, ratings for I and vi vary depending on Last Note. As for learners, there was a significant main effect of Chord: $F\ (6, 96) = 17.94$, $p < .001$, $\eta^2_p = .529$, but no significant main effect of Last Note or significant interaction between Chord and Last Note was found ($p = .233$ and .115, respectively). Ratings for non-musicians were similar to those for learners, as in both cases there was a significant main effect of Chord: $F\ (6, 90) = 2.28$, $p = .047$, $\eta^2_p = .186$,

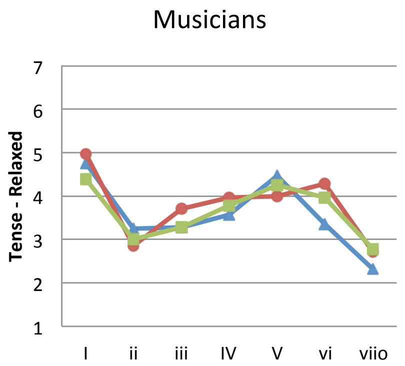

Figure 5.18. Musicians' mean ratings of Relaxation for Chord, Last Note, and Musical Background

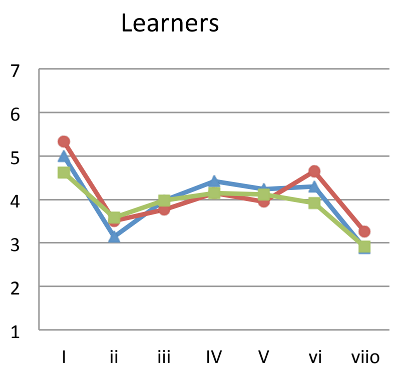

Figure 5.19. Learners' mean ratings of Relaxation for Chord, Last Note, and Musical Background

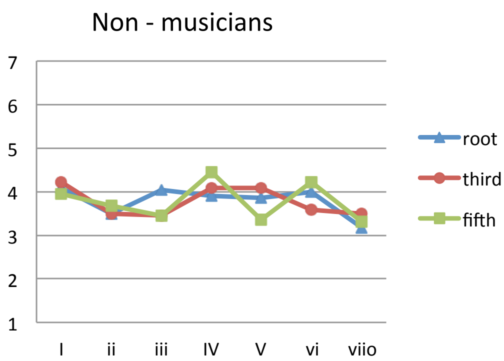

Figure 5.20. Non-musicians' mean ratings of Relaxation for Chord, Last Note, and Musical Background

no significant main effect of Last Note, and a significant interaction between Chord and Last Note (p = .987 and .108, respectively).

A one-way ANOVA with the effect of Musical Background revealed that among 21 conditions (7 chords and 3 last notes), there was a significant main effect of Musical Background on the ratings of the following four sequences; I with the fifth note: F (2, 39) = 3.58, p = .037; vi with the root: F (2, 39) = 3.29, p = .048; vi with the fifth: F (2, 39) = 4.09, p = .024; vii^{o} with the root: F (2, 39) = 3.51, p = .040. Learners' Relaxation ratings tended to be higher than those of musicians and non-musicians, apart from for sequences ending with vii^{o} and the root, which non-musicians rated as more relaxed than learners and musicians.

Interaction between Last Note, Augmented, and Musical Background

A two-way ANOVA was carried out on the Relaxation ratings of participants of each level of Musical Background, with Chord averaged, and the mean ratings are shown in Figures 5.21, 5.22, and 5.23. For musicians, there was no significant main effect of Last Note (p = .075), but a significant main effect of Augmented was found: F (1, 13) = 34.28, p < .001, η^2_p = .725. There was no significant interaction between Last Note and Augmented (p = .572).

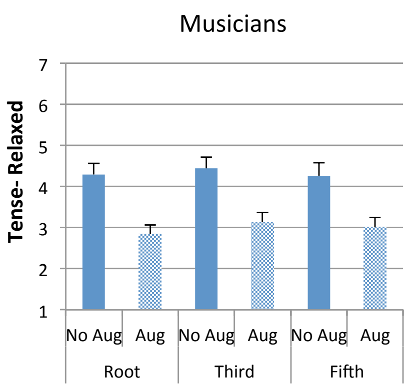

Figure 5.21. Musicians' mean ratings of Relaxation for Augmented, Last Note, and Musical Background

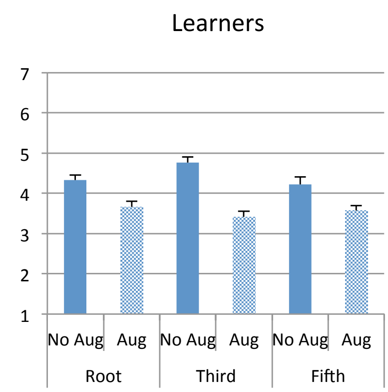

Figure 5.22. Learners' mean ratings of Relaxation for Augmented, Last Note, and Musical Background

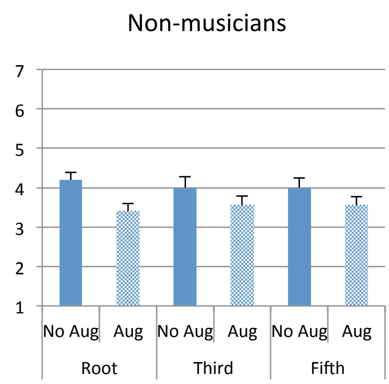

Figure 5.23. Non-musicians' mean ratings of Relaxation for Augmented, Last Note, and Musical Background

As for Learners, again there was no significant main effect of Last Note (p = .233), but there was a significant main effect of Augmented: F (1, 16) = 30.68, p < .001, η^2_p = .657. There was also a significant interaction between them: F (2, 32) = 10.16, p < .001, η^2_p = .388, as the effect of Augmented differed depending on Last Note. The difference between with and without Augmented was larger for sequences ending on the third than for the other two. Non-musicians' results were similar to those of musicians, for whom there was no significant main effect of Last Note (p = .987), but a significant main effect of Augmented: F (1, 10) = 12.85, p = .005, η^2_p = .557. There was no interaction between Augmented and Last Note for non-musicians' Relaxation ratings (p = .344). There was a significant main effect of Augmented for all groups, although the size of this effect varied from group to group: it was largest for musicians, and smallest for non-musicians, which means that the difference between the ratings of sequences with and without Augmented was larger for musicians.

A one-way, between-subjects ANOVA with Musical Background was carried out. There was a significant main effect of Musical Background on Relaxation ratings for sequences without Augmented ending with the root: F (2, 39) = 5.19, p = .010, as musicians rated this sequence more tense than the other two groups did.

Table 5.5

Each group's correlation between the ratings for Consonance, Pleasantness, Stability, and Relaxation.

		Consonance			Pleasantness			Stability		
		Musicians	Learners	Non-musicians	Musicians	Learners	Non-musicians	Musicians	Learners	Non-musicians
Pleasantness	*r*	.933	.862	.662						
	p	<. 001	<. 001	<. 001						
Stability	*r*	.910	.930	.774	.889	.870	.708			
	p	<. 001	<. 001	<. 001	<. 001	<. 001	<. 001			
Relaxation	*r*	.917	.849	.624	.878	.816	.623	.889	.885	.613
	p	<. 001	<. 001	<. 001	<. 001	<. 001	<. 001	<. 001	<. 001	<. 001

Correlation

In order to examine the extent to which listeners perceive and evaluate Consonance, Pleasantness, Stability, and Relaxation in the same way, Pearson's product-moment coefficient was computed for each group. As can be seen from Table 5.5, the results show that within each of the three participant groups, ratings for the four variables are highly correlated (r = .623 to.933, p < .001). Unlike Experiment 5, musicians' ratings for C/D do not differ from their ratings of the other three variables, and neither are they substantially different from the ratings of the other two groups. In fact, Pearson's correlation coefficient for musicians was the highest of the three groups, while non-musicians' correlation was the lowest.

Regression

A Stepwise Linear Regression was computed in order to assess the influence of additional factors related to the horizontal motions of the realised intervals, which could not be included in the ANOVA. Six variables were factored in: "Augmented" – whether or not

Table 5.6.

Summary of the results of Regression Analysis

	Consonance R^2adj = .842			Pleasantness R^2adj = .839			Stability R^2adj = .781			Relaxation R^2adj = .766		
Variables	Standardised Coefficient	*p*	Partial Correlation	Standardised Coefficient	*p*	Partial Correlation	Standardised Coefficient	*p*	Partial Correlation	Standardised Coefficient	*p*	Partial Correlation
Augmented	- .766	**<. 001**	- .892	- .848	**<. 001**	- .906	- .682	**<. 001**	- .831	- .648	**<. 001**	- .808
Chord types	- .513	**<. 001**	- .798	- .403	**<. 001**	- .722	- .571	**<. 001**	- .781	- .598	**<. 001**	- .785
Jump	- .144	.066	- .293	- .060	.351	- .154	- .088	.237	- .191	- .124	.102	- .262
Direction	- .117	.061	- .298	- .048	.461	- .121	- .081	.278	- .176	- .119	.120	- .250
Shared tones	- .101	.113	- .255	- .137	**.040**	- .327	- .135	.072	- .288	- .086	.264	- .181
Interval C/D	- .106	.134	- .241	- .017	.824	- .037	- .144	.082	- .279	- .125	.148	- .233

the second chord was augmented (“1” = without an augmented chord, “2” = with an augmented chord); “Chord Type” – the type of last chord heard (“1” = major chord, “2” = minor chord, “3” = diminished chord); ”Distance” - the size of the realised interval (“0” = a small realised interval, i.e. less than 2 semitones, “1” = larger realised intervals, i.e. more than 2 semitones); “Direction” - the direction of the top note from the middle to the third chord (“0” = small upward or downward movement, i.e. within 2 semitones, “1” = downward movement of more than 2 semitones, “2” = upward movement of more than 2 semitones); “Shared Tones” – the number of shared tones between the second and third chords (0 to 3); and the C/D of the realised interval (“1” = tritone, “2” = minor seconds, “3” = major seconds, “4” = minor thirds, “5” = major thirds, “6” = the perfect fourth, “7” = unison). The results are summarised on table 5.6, which shows that the Augmented variable explains all four ratings rather well (since more than 40% of the variance is explained across the ratings). Augmented was negatively correlated with these ratings, indicating that the existence of an augmented chord in a sequence lowered its ratings (that is, it made for more negative ratings). All four ratings were also predicted by Chord Type, and, with Augmented and Chord Type, more than 75% of the variance was explained. As with Augmented, Chord Type negatively correlates with the ratings, as a diminished or minor chord made listeners evaluate a sequence as more dissonant, unpleasant, or unstable. For the C/D ratings, the *p*-values for Distance and Direction were close to being significant, which may imply that they would have been significant predictors had the data set been larger. As for ratings of Pleasantness, it was found that Shared Tones was also a significant predictor, and, together with Augmented and Chord Type, it explains 85.1% of the variance. Shared Tone was also negatively correlated with ratings, suggesting that an increase in the number of shared tones between the second and third chords led to a more negative rating.

5.6.3. Discussion

A mixed three-way ANOVA again confirmed the effects of Augmented and of Last Note. Sequences with an augmented chord were perceived more negatively than those without, as in Experiment 5. Also, sequences whose last top note was the fifth of the final chord were perceived as more dissonant, unpleasant, unstable and tense, which is consistent with the results of Experiment 5. It might be the case that the fifth note fails to induce enough of a sense of closure to the cadence, and perhaps instead its dominant character triggers a desire to move to the tonic. However, as in Experiment 5, the Start Note was found to have no effect. It might be that the last note is more important to the listener than the start note as it confirms the character of the whole sequence, and also because of order effect - listeners will have a better memory of what they have just heard than what they heard a few seconds or minutes ago (Snyder, 2000). A detailed look at the interaction between Chord and Last Note revealed that, regardless of whether the last note is the fifth or not, a sequence tended to be more consonant and pleasant when the top note of its middle chord was anchored by a tone close in pitch - in other words, when its realised interval was smaller. This tendency is consistent with the pitch proximity principle.

On the other hand, Regression Analysis did not show that the size of a realised interval (Distance) was a good enough predictor of listener perception, although it was close to being a significant predictor in the case of C/D ratings. Instead, analysis brought to light the strong influence of Augmented as we have already seen, and it also helped to highlight the importance of the C/D of the final chord as a predictor of listener perception. This latter issue will be discussed in the section on the size, direction, and C/D of realised intervals.

Tonal hierarchy

The results reveal the strong influence of the tonal hierarchy of the final chord on the perception of the whole sequence. As predicted, sequences ending on the tonic chord, I, were perceived as most consonant, pleasant, stable, and relaxed, followed by sequences ending with IV, vi, and V. By contrast, sequences ending with ii and iii were negative, in particular those with a leading tone chord vii^{o} were perceived most dissonant, unpleasant, unstable and tense. This result is consistent with the experimental data of Krumhansl (1990), in which listeners rated I as best fit in the context of a prime in a major key, followed by IV, and V, mirroring the tonal stability and importance of the seven diatonic chords in a major key. Besides fitting with Krumhansl's experimental data, the result is also consistent with the various common harmonic progressions in music theory (Piston, 1950), and with statistical data on typical progressions following a chord of V (Budge, 1943; De Clercq & Temperley, 2011; Rohrmeier & Cross, 2008). These considerations strongly suggest that listeners have a firm implicit knowledge of tonal hierarchy and of acceptable harmonic progressions based on the frequency of their occurrence and through everyday listening, and that they made use of this implicit knowledge to judge and evaluate the chord sequences presented in the experiment.

Psychoacoustic similarities

By comparison, psychoacoustic similarities between the middle and third chords seemed to be a less influential factor than tonal hierarchy. The rank order of pitch commonality between V and the succeeding chord was not consistent with listeners' ratings. Sequences ending in chords that had a high pitch commonality with V, such as iii or ii, were rated as more dissonant, unpleasant, unstable and tense than sequences with lower pitch commonality, such as I or vi. Previous studies report that tonal hierarchy has a greater influence than the acoustic features of sound on the perception of chord sequences, while the opposite has been found in the case of isolated chords or short chord sequences (Parncutt & Bregman, 2000; Tekman & Bharucha, 1998; Thompson & Parncutt, 1997). The results from the present study, therefore, which finds that tonal hierarchy is of greater importance than the psychoacoustic similarities between chords, can perhaps be explained by the fact that the sequences used were long enough to establish tonal context. Regression analysis revealed that the number of shared tones only had an influence on Pleasantness ratings, and its standardised coefficient reveals that the more tones there were in common between two successive chords, the less pleasant listeners judged the sequence to be. This finding – of a negative relationship between the numbers of shared tones and listeners' ratings - contradicts the prediction based on psychoacoustic similarities, and perhaps suggests that the influence of the tonal hierarchy is more significant than the influence of psychoacoustic similarities. After all, a V chord has few or no tones in common with harmonically related chords such as I and IV, while V shares two tones with vii^{o} and iii which are harmonically distant from V and least important of all.

Varieties of final chord

Regression analysis revealed that the variety of last chord was a strong predictor of listener ratings: a sequence was rated more consonant, pleasant, stable, and relaxed when the final chord was major as opposed to diminished. This result is consistent with the results from Experiment 1 in Chapter 3. It is also important to note that different chords not only have different levels of C/D, but that they also perform different functions in the tonal hierarchy. In major keys, major chords are in important and stable positions such as I, V, and IV, while minor chords are in less important and stable positions such as vi, ii, and iii (however, in minor keys, minor chords do perform important functions). The weakest diatonic chord, the leading-tone vii^{o}, is a diminished chord. This is not surprising, since major and minor triads can both perform the function of opening and closing the cadence as a tonic, which increases their importance and stability as well as their level of consonance. The dominance of major and minor triads may derive from their prevalence in music. According to Parncutt (2011), major and minor triads were already common in the 15th century, and composers used these triads in correspondence with the prevalence distribution of pitch chroma. As a result, major and minor chords accompany more important tones, which had the effect (or so it might be thought) of increasing their own importance and stability over time. This also strengthened the correspondence between the distribution prevalence of pitch chroma, the distribution prevalence of chords, and the hierarchy of perceived stability (Parncutt, 2011).

Size, direction, and C/D of realised intervals

As for hypotheses regarding realised intervals, the detail of the interaction between Chord and Last Note shows that, for realised intervals between the middle and final chords, last notes that are closer in pitch to the previous note were preferred to notes farther in pitch. This is accordance with the pitch proximity principle, and with the results of Bigand et al. (1996), which show that smaller pitch distances make for reduced tension ratings. In most cases, sequences ending with last notes which were same as the immediately preceding note, and sequences ending with notes no more than 2 semitones above or below the previous note, were rated more positively than sequences whose last note was more than 2 semitones above or below the previous note. One exception was the sequence in the key of C major that ended with a V chord that had a realised interval *d-g* - this was judged more positively than intervals *d-d* and *d-b*, despite *g* being the furthest note from *d*. This may be explained by the fact that *g* is the root of chord V, and the dominant note in the key of C major, and it thus lent the cadence a sense of stability and closure that the supertonic and leading-tone note were unable to provide.

With regard to the direction of realised intervals, a mixed three-way ANOVA revealed neither a significant main effect of Start Note nor a significant interaction between Start Note and Last Note. This implies that the direction of the implicative and realised intervals, and thus the theory of pitch reversal, had no bearing on listener ratings. The failure of the theory of pitch reversal to predict listener ratings might be explained by the fact that the realised intervals used in this experiment were not large enough to make a significant difference. Schellenberg et al. (2002) stipulated that large intervals are ones that involve a leap of more than 5 semitones, and the largest intervals in this experiment were 5 semitones above or 6 semitones below the previous note. Also, regression analysis showed that *p*-values for Distance and Direction were not significant, although they were close to being significant in the case of C/D ratings. This suggests that if the sizes of intervals had varied more (e.g. if sixths and sevenths had been included), then Distance and Direction might have been good predictors of listener ratings.

Regression analysis further revealed that the C/D of realised intervals did not explain listener ratings either. The reason that the fourth hypothesis regarding realised intervals (as discussed under 'Experiment 6'), which includes the C/D of those intervals, did not predict well may be that listeners paid much more attention to the vertical structure of chords and to their harmonic functions rather than to the horizontal motions between chords. Listeners were presented with sequences consisting of three chords, in which the length and loudness of each tone was equal. As such, there was nothing to make the melody line stand out above the chord sequence, and therefore listeners may not have been sufficiently aware of the horizontal motion of the sequence.

The effect of Augmented and Musical Background

The most predictable and most marked finding is that the existence or absence of an augmented fifth for the middle chord significantly influenced listener perception. As the results of Experiment 5 demonstrate, sequences with an augmented fifth were perceived as more dissonance, unpleasant, unstable and tense than those without, irrespective of the listener's musical background. However, there was a slight difference between participant groups: the effect of Augmented was found to be larger for musicians than for learners or non-musicians. The difference between pleasantness and unpleasantness ratings, and between relaxed and tense ratings were wider for musicians than for non-musicians, indicating that musicians perceived pleasantness and relaxation as being more pleasant and relaxed, and unpleasantness and tension as being more unpleasant and tense, than non-musicians did. This greater range of perception among musicians was also found in chords in isolation (Chapter 2).

5.7. Conclusion

In summary, Experiment 6 demonstrated that the tonal importance and stability of the final chord influenced listener perception of the three-chord sequences, and further revealed that the more important and stable the last chord is in the tonal hierarchy, the more likely the listener will be to perceive the sequence positively. On the other hand, the results by and large failed to lend support to the hypothesis on the horizontal motion of realised intervals. Although there was a significant effect of Last Note on ratings, Regression Analysis revealed that the size of an interval in semitones, its direction, and its C/D all had little influence on listener perception. In other words, the anchoring from the top note of the middle chord to the top note of the final chord did not influence listener perception. This could be because the realised intervals used were not large enough, or because the soprano lines of the sequences were not distinctive enough. It might have been different had the soprano line been played using a different timbre - instead of just using chord sequences with a single timbre, a melody in a separate timbre accompanied by a chord sequence may have enabled listeners to be more aware of horizontal motion.

Chapter 6

Discussion and Conclusion

The six experiments in this thesis yield fruitful empirical evidence of the influence of non-acoustic factors in the perception of C/D. The main findings of this thesis are as follows. One and the same chord can often have varying levels of consonance and dissonance depending on context and familiarity, and so the C/D of chords is not simply a function of their auditory characteristics. The perception of C/D depends on various factors such as: the frequency of a chord's occurrence in a piece of music; the presence or absence of musical context; the function of the chord in question; the way in which a dissonant note is anchored by its following note; and the function of the following chord.

In this general discussion, I will review the main findings of this thesis, and discuss the research questions raised. I will also consider how the thesis contributes to our current knowledge, and highlight future directions for research.

6.1. Reviews and implications of main findings

6.1.1. Musical context

The primary question this thesis asks is whether the C/D of a chord ever varies according to the context in which it appears, and, in the case of chords that tend to be judged as dissonant at least, the answer we can divine from the findings is 'yes'. Chapter 4 revealed that the presence and absence of musical context changes the C/D level of chords: augmented and diminished chords were generally judged more consonant when appearing in musical context than when in isolation, but diminished chords appearing on the dominant were perceived as more dissonant than when in isolation. It was also found that the harmonic function on which these chords appear influences their C/D level: diminished triads were perceived as more consonant when on the subdominant than when on the tonic or dominant, which reflects the common harmonic convention that sees the diminished triad appearing as the leading-tone chord that precedes the tonic in order to close the cadence. Chapter 5 showed that the harmonic function of a chord following an augmented chord on the dominant also plays an important role in the listener's C/D perception of a chord sequence: sequences whose augmented chord on the dominant was anchored by a I chord were the most consonant, while those whose augmented chord was anchored by a vii^{o} or ii chord were the most dissonant. Not only is the harmonic function of the chord that follows the augmented chord an influential factor in shaping C/D perception, but the way in which the augmented tone is anchored by the tone that follows it is an influential factor as well. Chord sequences whose augmented tone was anchored by a tone that was stable and close in pitch were judged more consonant and pleasant, while sequences with a larger gap between the augmented and following tones were judged less pleasant.

These results demonstrate the significant role of tonal hierarchy and musical syntax in C/D perception. The influence of the implicit knowledge of tonal hierarchy and syntax, and the listener's expectations based on these - which have been acquired through exposure to a particular style of music - has been widely discussed. If the listener who is familiar with Western tonal music should detect a harmonic sequence that deviates from the norm and thus also from his musical schema, then they will process what they hear more slowly and less accurately (Bigand & Pineau, 1997; Bigand, Madurell, Tillmann & Pineau, 1999; Tillmann, Janata, Birk, & Bharucha, 2008; Tillmann &Lebrun-Guillaud, 2006; Tillmann & Marmel, 2013) and may also feel tension (Steinbeis, Koelsch, & Sloboda, 2006). Further, brain responses to an unexpected musical event elicit a large late positive component (Regnault, Bigand, & Besson, 2001) and large mismatch negativity (Brattico, Näätänen & Tervaniemi, 2002), and brain responses to the same chord differ according to whether its appearance follows or deviates from common harmonic practice (Koelsch, Gunter, Friederici, & Schroeger, 2000; Leino, Brattico, Tervaniemi, & Vuust, 2007; Loui, Grent-‘t-Jong, Torpey, & Woldorff, 2005; Maess, Koelsch, Gunter, & Friederici, 2001; Otsuka, Kuriki, Murata, & Hasegawa, 2008). This thesis adds to our understanding of the influence of tonal hierarchy on the perception of musical C/D, and provides further evidence of the ways in which tonal hierarchy and musical syntax shape our C/D perception. The chord sequences used as stimuli in Chapters 4 and 5 were short, consisting of only three chords, and they provided a musical context that was neither complicated nor rich. Nevertheless, the results from the experiments in these chapters clearly reveal just how much influence tonal hierarchy and syntax have in creating our perception of musical C/D. In the experiments in Chapters 4 and 5, the degree of perceived C/D and pleasantness/unpleasantness for chords and chord sequences varied depending on context, and listeners perceived chords and chord sequences as most consonant and pleasant when they followed common harmonic practices. These results highlight that the perception of chords is not solely determined by their acoustic features and by our auditory systems, but rather that it is also a product of learning that we acquire through a process of musical development.

6.1.2. Frequency of Occurrence

Chapter 3 revealed correlations between the frequency of a chord’s occurrence in a piece of music and its C/D level, and between listener familiarity with timbre and the C/D of chords. The more frequently a chord appears, the more likely it is to be perceived as consonant. This role that frequency of occurrence plays in musical listening has been reported in studies that have examined a wide variety of musical genres, such as classical music (Krumhansl, 1985), Indian music (Castellano, Bharucha & Krumhansl, 1984), Finnish Sami yoik (Krumhansl, Louhivuori, Toiviainen, Järvinen, & Eerola, 1999; Krumhansl, Toivanen, Eerola, Toiviainen, Järvinen, & Louhivuori, 2000; Krumhansl, 2000), and even artificial musical systems (Oram & Cuddy, 1995; Jonaitis & Saffran, 2009). These studies reveal that, as the listener begins to intuitively recognise the frequency with which certain tones and chords appear, they become able to understand the relationships between these tones and chords and can establish a tonal hierarchy, which in turn helps them to extract the underlying principles of the music and to understand its structure.

However, when it comes to the relationship between frequency of occurrence and C/D perception, the question of why the more frequent occurrence of particular chords should go hand in hand with a higher consonance level remains unclear. One view is that, as the listener becomes more familiar with more frequently appearing stimuli, they perceive it as being more pleasant and preferable (Huron, 2006). This effect of familiarity on our appreciation for objects has been reported not only in the auditory domains of language and music (Huron, 2006; Peretz, Gaudreau, & Bonnel, 1998), but has also been noted for visual information such as characters (Malinowski & Hübner, 2001) and human faces (Dubois, Rossin, Schlitz, Bodart, Michel, Bruyer, & Commelinck, 1999). Parncutt (2012) looks back on how historical changes in chord usage have helped to shape our musical schema, and explains that the listener comes to perceive certain chords and intervals as more acceptable and preferable as their use becomes more common. On the other hand, the relationship between the frequency of a chord's occurrence and its perceived level of consonance may derive from a preference for consonant chords. Generally, consonance is preferred over dissonance (McDermott et al., 2010; Bones, et al., 2014), and dissonance is treated as representing a deviation from consonance in music. As Hugo Riemann defined it, dissonance is ‘interference with the uniform conception’ (as cited in Tenney, 1988. p. 73). Therefore, the usage of dissonance tends to be avoided in Western tonal music (Vassalakias, 2005). On the basis of these findings, it is reasonable to think that intervals and chords that are considered consonant will be used more frequently than less consonant ones. In fact, as Huron (1991) demonstrated, Bach seemed to intentionally use intervals that were normally regarded as consonant, and to avoid using dissonant intervals in order to sustain the consonance level of certain of his keyboard pieces. Future studies will do more to tackle this issue of whether the frequency and consonance of chords are correlated due the effect of familiarity or because of a preference for intervals and chords that are already perceived as consonant.

6.1.3. The relationship between C/D and other concepts

Previous studies have revealed a congruency between C/D and pleasantness (Blood, Zatorre, Bermudez, & Evans, 1999; Koelsch, Kilches, Steinbeis, & Schelinski, 2006), have examined the relationship between C/D and stability (Bigand, Parncutt, & Lerdahl, 1996; Dibben, 1997; Lerdahl & Krumhansl, 2007), and have highlighted the contribution of dissonance to the perception of tension (Bigand et al., 1996; Bigand & Parncutt, 1997; Toiviainen & Krumhansl, 2003; Lerdahl, 1996, 2001; Lerdahl & Krumhansl, 2007). The behavioural data presented in this thesis reconfirms the traditional notion that the consonance of sounds is correlated with pleasantness and stability, while dissonance is correlated with perceived tension. As Chapter 5 demonstrates, when it comes to the perception of *chord sequences*, the four variables examined – consonance, pleasantness, stability, and relaxation - are highly correlated, and as such these variables seem on the face of it to denote one and the same quality of chords.

By contrast, Chapter 3 provides new findings that indicate that, when it comes to the perception of chords *in isolation*, two different aspects contribute to the perception of the four variables: the listener's perception of C/D and stability/instability was relatively more influenced by their knowledge of tonal hierarchy, while perceptions of pleasantness/unpleasantness and relaxation/tension were influenced more by the instrumental timbre and by the listener's familiarity with that timbre.

The perception of both C/D and stability is to some extent a knowledge-based, top-down process. The perception of C/D involves the processing of auditory information, and requires the decoding of the meaning and importance of that information within the frame of the tonal hierarchy. Likewise, stability is a concept that derives from the system of tonal music, and the listener's judgements of stability are heavily dependent on their musical schema in which their knowledge of the tonal hierarchy is stored. By contrast, the perception of pleasantness and tension may be a more bottom-up process: they are basic dimensions that help comprise the most fundamental and primitive levels of mood and emotion (Sloboda & Juslin, 2010). Tension is trigged both by the acoustic characteristics of sounds such as dynamics, tempo, C/D, and by listener expectations based on their musical schema (Koelsch, 2014), so perceiving musical tension involves both perceptual and cognitive processes. Still, tension and pleasantness arise at an early stage in the development of the listener's musical schema, prior to the development of more complicated stages such as perception or cognition of stimuli (Russell, 2003), and so it might be the case, therefore, that the acoustic features of chords will have a greater influence on their perception.

The contrast between the perception of pleasantness/unpleasantness and tension/relaxation on the one hand and the perception of C/D and stability on the other, - whereby the acoustic features of chords exerts a greater influence on the former while the listener's knowledge of the tonal hierarchy has a greater influence on the latter - may stem from the different perceptual (and, in the case of C/D and stability, cognitive) processes required for the judgement of these four variables. On account of this contrast in the perception of these variables, it is reasonable to suppose that they are co-occurring, perceptible features of chords, rather than one and the same quality under a variety of names.

The study in Chapter 3 also demonstrates that, in contrast to their less musically trained counterparts, musicians did not invariably perceive consonance as being pleasant, which is consistent with the findings of Guernsey (1928). It is interesting that this difference was more pronounced when chords were presented in isolation than when in context. The fact that chords in isolation contain less information and therefore fewer constraints than chords in context may have been what made the discrepancy between C/D and the other variables more pronounced.

6.1.4. The effect of musical expertise

The experiments in Chapters 3 and 5 reveal that there is a difference between musicians' and non-musicians' perceptions of C/D. Musicians demonstrated an ability to identify a greater variety of qualities and characters within chords, as has been reported in previous studies (Brattico, Pallesen, Varyagina, Bailey, Anourova, Järvenpää, Eerola, & Tervaniemi, 2009; Itoh, Suwazono, & Nakada, 2010; Roberts, 1986; Rogers, 2010; Schön, Regnault, Ystad, & Besson, 2005). Musicians also tended to perceive the C/D of isolated chords separately and independently from their perception of the other three variables, whereas learners' and non-musicians' perceptions of the four variables tended to be highly correlated with each other. This result is in accordance with the findings of a study by Guernsey (1928), in which musically trained listeners did not find intervals that they rated as smooth to be pleasant also, while non-musicians did. The findings reported in this study support the supposition that the listener's ability to process and perceive musical information is plastic, and that extensive musical training plays an important role in shaping and enhancing this ability (Bidelman, 2013).

In addition, the findings indicate that the effect of musical training on chord perception may depend on whether they appear in a musical context. While musicians' ratings of C/D did not correlate with other variables when they listened to chords in isolation (Chapter 3) or in a simple harmonic context (Experiment 1 in Chapter 5), C/D perception was highly correlated with all other variables across all participant groups when chords were presented in a context (Experiment 2, Chapter 5). The influence of musical training seemed to be more pronounced for chords with little or no musical context than for chords in a more complicated musical context. It is possible that chords in a musical context activate the musical schemata of both musicians and less musically trained listeners to the same degree. However, extensive musical training is likely to make for a more deeply-rooted understanding of tonal hierarchy and musical syntax, just as musical training can enhance a person's sensitivity to the physical dimensions of chords, and can 'override and exaggerate' auditory processing mechanisms (Bidelman, 2013. p. 9). So, a musician's musical schema and implicit knowledge of tonal syntax can still be activated by chords with little or no harmonic context, and so these factors can still influence their perception of single chords. However, a non-musician's musical schema will not be sufficiently activated by chords with little or no harmonic context, and so they will simply process these chords as sounds without being much influenced by musical schemata or any implicit knowledge of tonal hierarchy.

6.2. Contributions to Knowledge

Chapter 3 contributes to our knowledge of the perception of chords - both triads and tetrads - by examining three factors that influence their perception, namely, the frequency of their occurrence, their acoustic features, and the listener's familiarity with the timbre used. Although tetrads are commonly used in music, few studies on C/D employ them (Johnson-Laird, et al., 2012) probably due to their more complicated structure. This chapter presents rich behavioural data on the perception of different types of chord in isolation in terms of C/D, pleasantness/unpleasantness, stability/instability, and relaxation/tension, and reveals that even in the absence of a musical context, the perception of a chord is influenced by the listener's musical schema and not just by its acoustic features. The finding that chords judged to be consonant tended to occur more frequently provides behavioural evidence of a correlation between frequency of occurrence and C/D perception, thus supporting the findings of Huron (1991), and also supporting the idea that familiarity is one of the key factors in determining the C/D of chords (Cazden, 1980; Hair and Parncutt, 2011).

Another contribution of Chapter 3 is its examination of the relationship between the perception of C/D, pleasantness/unpleasantness, stability/instability, and relaxation/tension, which, to my knowledge, has never before been directly investigated. This study reveals both similarities and differences between these four variables. Listeners' perceptions of the four variables were highly correlated, although they differed slightly on account of the influence of the acoustic features of chords and listeners' knowledge of the tonal hierarchy. Listeners' knowledge of the tonal hierarchy influenced perceptions of C/D and stability more than it did perceptions of pleasantness and relaxation. The study also showed that more musically trained listeners judged consonance and dissonance differently. These findings suggest that consonance and pleasantness refer to two different aspects of a chord's character rather than to one and the same quality, and it helps to clarify the respective meanings of consonance and pleasantness, which are often treated as if they can be used interchangeably.

Chapter 4 advances our knowledge of the influence of expectation on chord perception by applying the theory of tonal expectation to the perception of musical C/D. Listeners judged chords as more consonant and pleasant when occurring on a more expected harmonic function of a sequence than when on a less expected function. This result is in accordance with the majority of expectation studies, which find that more expected stimuli are more quickly and accurately processed (Bigand and Pineau, 1997), and that the confirmation of expectation generates a positive affect (Huron, 2006). This study provides behavioural support to the findings from both behavioural and neuroscientific studies that show how our musical schemata and expectations shape our perception, cognition, and emotional experience of listening to music (Bigand, Madurell, Tillmann, & Pineau, 1999; Bigand & Pineau, 1997; Koelsch, Gunter, Friederici, & Schroeger 2000; Regnault, Bigand, & Besson, 2001).

Another contribution of Chapter 4 is the experimental method by which listeners judged the consonance or dissonance of chords in context when listening to the chord sequences. Most studies on the influence of tonal expectation use chord sequences in which the last one or two chords vary, and listeners must judge or rate these varying chords after hearing the sequence (Bigand, Madurell, Tillmann, &

Pineau, 1999; Bigand & Pineau, 1997; Tillmann, Janata, Birk & Bharucha, 2008; Tillmann & Lebrun-Guillaud, 2006). This experimental method has the disadvantage of restricting the possibilities for the manipulation of chords. By contrast, some studies employ a method whereby listeners can judge or respond to a chord while listening to a chord sequence (Bharucha & Krumhansl, 1983; Tillman & Marmel, 2013). This thesis adopted this judge-while-listening method because it made it possible for any chord in the sequence to be judged, and it allowed the data to reflect the real-time responses of listeners as they made their C/D judgements without being influenced by subsequent chords.

Chapter 5 contributes to our understanding of the role of anchoring in the perception of chord sequences. The effect of anchoring has mainly been discussed in terms of its influence on melodic expectation and melody perception (Bharucha, 1984, 1986; Narmour, 1992; Schellenberg, 1996, 1997). Studies concerning C/D and chord sequences mainly focus on the vertical structure of chords and on their harmonic functions (Cook & Fujisawa, 2006; Johnson-Laird, et al., 2012; Roberts, 1986), while the horizontal aspects of chords - such as melody line, pitch difference between successive notes, and the psychoacoustic similarities between two chords - have rarely been addressed. The study in Chapter 5 investigated the influence of anchoring and harmony - horizontal and vertical aspects, respectively - on the perception of chord sequences, and this yielded interesting results. The way in which a non-diatonic, dissonant tone is anchored by its succeeding tone and the size of the realised interval between these tones are factors that play an important role in chord sequence perception, and the harmonic function of each chord within the sequence was again shown to be an important factor. More importantly, these two aspects interacted with each other. Listeners perceived sequences ending on the root or third note in the top line as more consonant, pleasant, and stable than those ending on the fifth, although perceptions varied according to what was the final chord of the sequence. In the case of learners, the extent to which a sequence containing an augmented chord was perceived as tense varied according to the last note of the top line, and the difference between sequences with and without an augmented chord was larger for sequences ending on the third than for those ending on the root or fifth. The findings from Chapter 5 are largely in accordance with the principles of anchoring (Bharucha, 1984, 1986), of pitch proximity (Schellenberg, 1997), and of tonal hierarchy (Krumhansl, 1990), and the study serves as confirmation that the perception of chord sequences involves both horizontal and vertical aspects.

6.3. Future directions

The experiments presented in this thesis yield valuable empirical evidence on how the perception of musical C/D is influenced by a variety of factors not directly related to the acoustic features of chords. These factors include: the frequency of a chord's occurrence; the harmonic function of a chord; the harmonic context in which a chord appears; the way in which the non-diatonic tone of a dissonant chord is anchored by its following tone; and the harmonic function of the chord that follows a dissonant chord. The findings from this thesis raise questions that require future study.

6.3.1. Individual differences

The results from the experiments in this thesis consistently reveal that the syntax of Western tonal music is deeply established in the listener's musical schema, and that the explicit and implicit knowledge of tonal music helps to shape their perception of C/D both in isolation and in a context. This thesis focuses on simple and basic harmonic progressions, ones that commonly appear in a wide variety of genres and styles of music. The question that arises here is whether C/D perception differs according to the listener's taste in music – that is, whether listening to a certain genre or specialising in a particular type of music would have an effect on C/D perception. Studies concerning the statistical distribution of different types of chord have shown that there are differences in the frequency of the occurrence of particular chords and harmonic progressions across different genres of music, such as baroque, classical, rock, and jazz (Bronze & Shanahan, 2013; Budge, 1943; De Clercq & Temperley, 2011; Huron, 2006; Rohrmeir and Cross, 2008). For instance, by comparison with classical music from the 17th to the 19th century, modern jazz tends to use a greater variety of chords and harmonic progressions, which are sometimes regarded as forbidden according to the rules of classical music. Taking this into consideration, it is possible that the listener's musical schema will vary depending on their preference for musical genre, since what they listen to most often will shape their musical schema and thus influence their perception of music. If this is the case, then what listeners perceive as consonant or dissonant, or as pleasant or unpleasant, will vary: chords that the jazz lover hears as pleasant and harmonious may be too dissonant for the classical music listener to perceive as pleasant, or vice versa.

6.3.2. Contrastive valance

This study confirms that, although consonance and pleasantness represent different features of chords, perceptions of these two variables are generally very similar. This raises the question of whether there can ever be a pleasant dissonance or a pleasure created by dissonance. Huron (2006) finds that a greater degree of pleasure will be triggered following an unexpected musical event that is resolved by an expected outcome, a phenomenon termed 'contrastive valance'. This notion of contrastive valance could be applied to the pleasure and consonance triggered by the contrast between dissonance and consonance. It may perhaps be the case that the higher the level of dissonance, the greater the amount of pleasure and consonance that will be induced when the dissonance is resolved. The level of dissonance may depend on several factors, such as: the acoustic features of the dissonant chord, the expectedness of the harmonic context in which the dissonance appears, and the timing and length of the dissonant chord. As an illustration of this last factor, if the dissonance is sustained and the resolution to consonance is postponed over several bars (such as in the opening to Wagner's *Tristan und Isolde*), the level of dissonance would increase, and more pleasure would be induced when the dissonance is finally resolved.

Future work could address this hypothesis by manipulating the types of dissonant chord, the harmonic context, and the length of the dissonance. The stimuli could include harmonic reductions of real pieces of music instead of simple harmonic progressions, and continuous rating may be a good method of measurement. In this method, listeners slide a bar on a computer in response to stimuli as they listen, and it is commonly used in music emotion and tension studies (Toiviainen & Krumhansl, 2003; Lehne, Rohrmeier, Gollmann, & Koelsch, 2013). Continuous rating would allow for a more accurate reflection of real-time listener responses to continuously changing stimuli than a rating on a categorical scale or a semantic differential, and would make it possible to record the listener's continuously changing perceptions of the consonance and dissonance level of the stimuli. This future work could help to uncover how the contrastive valence of C/D operates, and could increase our understanding of the ways in which dissonance can induce pleasure in listeners. This in turn will advance our knowledge of musical C/D as a whole, and will aid our understanding of how consonance and dissonance influence the listener's perceived and felt emotions.

6.4. Conclusion

This thesis provides rich behavioural data on musical C/D, and demonstrates that musical context, the harmonic function of a chord, the frequency of a chord's occurrence, and the anchoring of tones all play a part in forming our perception of C/D. It also demonstrates that, contrary to the common belief which holds that consonance is unvaryingly pleasant, perceptions of consonance and pleasantness derive from different features of chords and do not always correlate. As for differences between the perceptions of musicians, learners, and non-musicians, the experiments reported here show that musicians are better able to discern different types of chord and chord sequence, which contributes to our understanding of the plasticity of perception and the potential for its enhancement through musical training. The findings of this study all suggest that, while there is to some extent a universality and innateness to the perception of C/D due both to the physical characteristics of music and to our auditory system, it is even so a diverse phenomenon which is largely created by the listener's schema.

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